WEB-BASED CONSTRUCTION DOCUMENT PROCESSING THROUGH A "MALLEABLE FRAME"

By

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To my wife Li Li

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Major Department: College of Architecture

Information management is critical to the success of a construction project. Because of the fragmentation of the construction industry and the diversity of construction projects, information sharing and collaboration are important measures to achieve successful project information management. As Internet based technology, such as the WWW (World Wide Web), e-mail, e-commerce, e-bid and e-Builder™, becomes ubiquitous, many practitioners in the construction industry believe that the Internet is the way to go for managing and disseminating construction information.

Currently Web-based applications have greatly relieved problems caused by geographical fragmentation; however these applications are not designed to deal with problems caused by functional fragmentation. Consequently, documents prepared using a third-party software tool cannot be directly used to retrieve related information in the viewer's local system.

This research treats a document as a "malleable frame" that can be adjusted according to user's needs and shows that a "malleable frame" system is more efficient in terms of processing construction documents than a standard system.

The research shows that a "malleable frame" system is technically feasible. The key is to have a neutral data format. Currently XML (eXtended Markup Language) related technology can be used to build such a neutral data format. In addition, many kinds of implementation tools, such as Java, DHTML (Dynamic Hypertext Markup Language) and COM (Component Object Model), are now available. It is inconclusive as to whether using the "malleable frame" system is more efficient than using the standard system. If document processing does not require local information or the required information is not available locally, the "malleable frame" system does not perform better than the standard system does. Nevertheless, if local information required by document processing is available, the "malleable frame" system performs at least as good as the standard system does.

CHAPTER 1
RESEARCH OVERVIEW

1.1 Research Objectives

The goal of this research is to study the feasibility of developing a "malleable frame" system by using available computer technologies and to propose methodologies for developing the "malleable frame" system. Also, the relationship between the malleability of a system and the efficiency of processing a document needs to be studied to determine whether the malleability provided by the "malleable frame" system is superior to a system without malleability.

To achieve the goal, a series of objectives has to be achieved. These objectives include:

1. Identifying new Web technologies that support the idea of a "malleable frame."
2. Identifying methods for developing the "malleable frame."
3. Applying the identified method to develop a "malleable frame" based on a sample construction document (a use case).
4. Identifying methods for developing the "malleable frame" system.
5. Applying the identified method to develop the "malleable frame" system based on the "malleable frame" developed.
6. Testing the idea of malleability.

1.2 Research Hypothesis

There are many features that a "malleable frame" can provide, while a standard system cannot. Those features include allowing a user to customize document presentation and automatically retrieve related local information. This research is focused on the second feature. It is this feature that makes a "malleable frame" system different from a standard system in that a standard system usually puts a received document and related local information in separate windows while a "malleable frame" system can put local information right beside a related information object of the document. Therefore, the hypothesis of this research is that (H_0): if we allow a document and related local information be put together (in the same window), the improvement in terms of time for completing a stage transition will be significant. If μ_m and μ_s are population means of time for completing stage transition for the "malleable frame" system and the standard system respectively, this hypothesis can be represented by a null hypothesis (H_0) and an alternative hypothesis (H_a).

$$H_0: \mu_s - \mu_m = 0$$

$$H_a: \mu_s - \mu_m > 0$$

H_0 states "there is no difference between the 'malleable frame' system and the standard system in terms of time for completing a stage transition." H_a states "the 'malleable frame' system is better than the standard system in terms of time for completing a stage transition."

Construction document processing involves a series of steps. For example, a complete change order process involves the step from a Request for Change Order Proposal to a Change Order Proposal. A stage transition is one of those steps.

1.3 Research Scope

Theoretically a "malleable frame" system can be used by any construction professional to deal with any kind of construction document in any kind of construction project. In order to narrow the scope of this research, the research scope will be defined in terms of intended users, the type of construction documents, and local information considered for test cases.

1.3.1 Intended Users

Different project professionals may have different project information needs. The perspectives of different users towards the same set of information may be different too. This research is focused only on the needs of construction site managers and site engineers when dealing with a certain construction document. Since the mechanism of how to adjust perspectives according to a user is similar, the mechanism used in this study can be applied to build systems for other project participants.

This research will not try to predict the user's information needs when dealing with a certain document. Instead, this research will assume that a user may need certain types of information for dealing with a given construction document.

1.3.2 Type of Construction Documents to Be Studied

Roughly, construction documentation can be divided into three phases, pre-construction, construction and post-construction (Mincks, & Johnston, 1998). This research focuses on documents such as change orders, shop drawings and RFIs during the construction phase in which new information is generated and recorded for project control and administration. Actually, this research will use the Request for Change Order Proposals (RCOP) as a test document to develop the "malleable frame" system. This does

not mean that the methodology developed based on the Request for Change Order Proposals cannot apply to other documents. The Request for Change Order Proposals were selected only because they are common cases that project managers and site engineers encounter very often. The Request for Change Order Proposals suit the problem that this research describes very well, because the Request for Change Order Proposals often refer to certain building components or construction activities and users information from many sources.

The whole process of dealing with construction change orders involves many steps. It will be redundant to study all steps of the whole process. Since this research uses the Request for Change Order Proposals for the development of a "malleable frame" system, naturally one step of the whole process is selected. Accordingly, a stage transition between the RCOP (Request for Change Order Proposal) and the COP (Change Order Proposal), will be studied.

1.3.3 Local Information Considered for Test Cases

For a project manager or a site engineer to properly process a Request for Change Order Proposal, he/she may need many different types of information that can be found in schedules, budgets, specifications, drawings, estimates and so on. In this research, only schedule information will be considered.

1.4 Research Significance

Traditionally, construction information sharing and the document production are tied together (Abou-Zeid, Russell, Hanna, & Park 1995, Finch, Flanagan, & March, 1996). Such approaches limit the participant's ability to interact with the information source and thus also limit the possibility of improving information sharing. This research

offers a profound change in the way that project participants share information. It essentially cuts the link between data and information presentation. The new approach allows a user centered approach in which users can tailor the information, rather than just passively use the information whose content and format are out of their control.

This research treats construction documents as media rather than end products. Usually, documents represent the end of a document production process. Other processes are treated separately. If other processes need information, normally another interpretation process, either by man or by machine, is necessary. This interpretation is a waste (Porter, 1980, Betts, 1995, Turk, 1997). In this research, documents are treated as vehicles of extendible objects, which can quickly integrate with other objects in an appropriate way and directly support other processes without any intermediate processes.

1.5 Research Methodology

Many computer-related studies find that it is very difficult to quantify the performance or results of information technology (IT) because of two reasons (Li, 1996). First IT usually adds value to other activities rather than delivering benefits directly. Second IT often gradually accrues to a construction organization as a whole and is not always visible as improvements in a short term. This makes it very difficult for quantitative hypothesis testing of academic research studies. In fact some even argue that since there are so many methods to develop computer-based applications and there are already so many computer tools out there, it really depends on users to decide if a new approach is better than the others and proper to them. Such arguments indicate that it will be enough for a computer application research study to just present a technically feasible solution. However, there is another completely different view emphasizing the

importance of classic scientific research methodology even for the computer application research (Harriss, 1998, Wing, Raftery, & Walker, 1998). For this research, a compromise is made, which means that this research will develop a prototype system to show the technical feasibility and also develop a test system to test the hypothesis.

The research methodology employed in this dissertation consists of several major phases including literature review, development of a "malleable frame," the "malleable frame" system design and implementation, system testing, and conclusions and recommendations. Figure 1.1 is a flowchart illustrating the methodology of this research. The phases are briefly discussed below.

1.5.1 Literature Review

This phase of the research is mainly focused on gathering information generated by previous studies in order to identify new Web technologies that support the idea of a "malleable frame", identify methods for developing a "malleable frame" and identify methods for developing "malleable frame" systems. In addition, other related subjects are also looked into. Following is a list of areas that the literature review covers

- Construction information and information management
- Current computer applications in construction practice
- Computer mediated communication and computer supported collaborative work
- Construction documentation
- Web-based systems
- SGML and XML
- Hypermedia Design
- Statistical Analysis

It needs to be pointed out that this dissertation puts the results of the literature study in related chapters and sections rather in one chapter.

1.5.2 Development of "Malleable Frame"

In the technical sense, a "malleable frame" is equivalent to a document type definition (DTD) or document schema. The DTD defines the structure of a document, and what and how information should be included in the document. Such a DTD is a generic document template from which document instances can be generated. Therefore, developing a DTD for a Request for Change Order Proposal is the very first step of this research. Major steps of this phase include

- Define the goal for developing a DTD
- Analyze document needs
- Design document type requirements
- Complete the design of a DTD

1.5.3 "Malleable Frame" System Design

During this phase, focus is given to the architecture of the "malleable frame" system. Major activities involved in this phase include

- Identify major hypermedia development methodologies and tools
- Define requirements of a hypermedia system to be developed
- Define the overall architecture of the "malleable frame" system

1.5.4 System Implementation

A prototype "malleable frame" system is implemented during this phase. The system shows how current Web technologies can be used to build such a "malleable

frame" system. The major tasks of this phase are to implement the system by using the Java programming language.

1.5.5 Hypothesis Testing

In this phase, focus is given to prove the hypothesis stated previously. Two types of test systems, a standard test system and a "malleable frame" system are built in order to test the hypothesis. It should be noticed here that it is very difficult to test the "malleable frame" itself. Rather tests will be about one of the effects of malleability. The tests are to find the time difference between the two systems, the standard system (SS) and the "malleable frame" system (MFS). For the testing purpose, schedule information will be used. In the standard system, users need to synthesize information to find out what decision to make. In the "malleable frame" system, related local information is put in the same window with the Request for Change Order Proposal therefore users do not need to find and synthesize information. For both systems, a built-in timer is used to keep track of time. Please refer to the chapter, "Hypothesis Testing," for details. The main steps of this phase are

- Define test plans
- Select test cases
- Set up test systems
- Define sample and sample size
- Collect data and information
- Statistical analysis

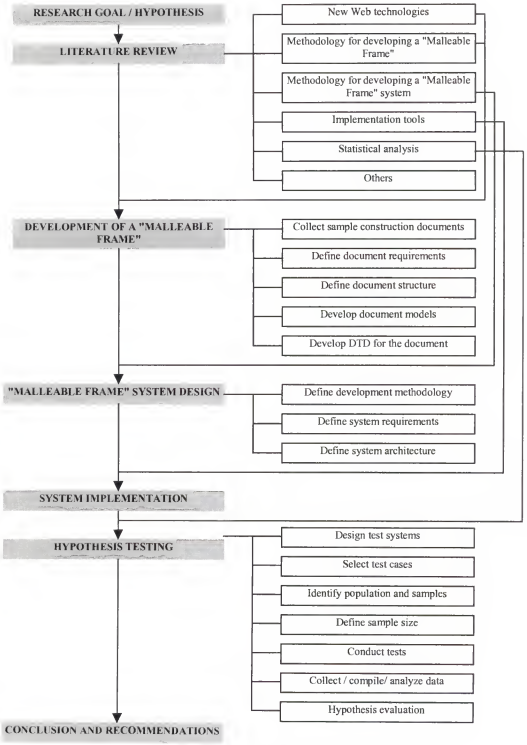


Figure 1.1 A flowchart illustrating research process

CHAPTER 2
LITERATURE REVIEW

2.1 Fragmentation of the Construction Industry

Fragmentation is one of the distinct characteristics of the construction industry (Howard, Levitt, Paulson, Pohl, & Tatum, 1989). According to Porter, any production process can be viewed as a value chain. Each time a product is worked on in some way or another, not only are resources consumed in that operation but also value is added to the product (Porter, 1980). "These processes include not only the direct processes which cause a physical alteration of the product but also such processes as moving the product from one place to another "(O'Brien, 1993, p. 446). To be as efficient and effective as possible, intermediary processes that do not add value to the entire process, such as moving the product should be reduced to the minimum level.

However, the value chain of a construction process is fragmented by at least two factors in general, geographic fragmentation and functional fragmentation (O'Brien, & Al-Soufi, 1993). The geographic fragmentation is caused by the fact that most of the construction projects are based on temporary collaborations of owners, architects, contractors, subcontractors and suppliers. In addition the locations of the projects and the locations of these partners are usually geographically different, sometimes thousands of miles apart. The functional fragmentation can be noticed when project partners take different roles throughout the entire construction process. For instance, architects,

engineers, contractors, subcontractors, suppliers and so on may join the team at different stages of a construction process. Even within a construction company, the functional fragmentation exists because of different roles of schedulers, estimators, superintendents and project managers. It is thus obvious that fragmentation permeates every aspect of the construction industry and segments an entire construction process, construction operations and management, and project partners into different phases, various functional and management groups, and different professional roles (O'Brien, & Al-Soufi, 1993). Therefore, some intermediary processes such as effective and efficient communication between project partners are necessary and essential for the success of a construction project (Brandon, & Betts, 1995).

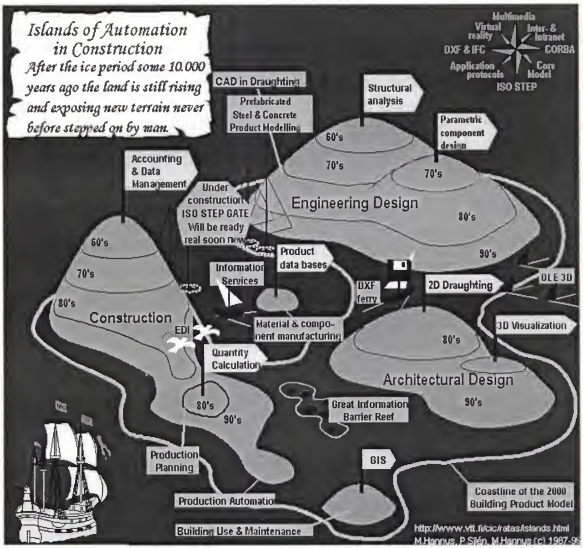
One of the main purposes of communication between construction partners is to share information. However, information sharing in the project construction context is a necessary evil. On the one hand fragmentation requires information sharing. On the other hand fragmentation itself is the major obstacle for information sharing. Research has already shown that, in the construction industry, data provided by one value-adding process is rarely in a format suitable for subsequent downstream processes (Ndekurgi, & McCaffer, 1988, Scott, 1995). This can be viewed as data fragmentation in general. A classic example of such problems is the WBS (Work Breakdown System) for scheduling and the CBS (Cost Breakdown System) for estimating. Because of different levels of details, the two systems cannot communicate with each other without some intermediary processes (Abudayyeh, & Rasdorf, 1991). Generally, data fragmentation is a derivative of geographic fragmentation and functional fragmentation.

Data fragmentation is a focus of CIC (Computer Integrated Construction) research (Brandon, & Betts, 1995). Electronic information sharing holds the promise to overcome the inefficiencies caused by fragmentation. Research suggests that benefits from electronic information sharing include a reduction in time requirements and errors for data input and output, accelerated communication among participants, and improved completeness of information received by each team member (Teicholz, & Fischer 1994). However, most current software solutions for drafting, scheduling, estimating and project document management can only expedite the particular functionalities for which they were designed. They barely solve the problem of data fragmentation that leads to what is called "Islands of Information" as shown in Figure 2.1 (Hunnas, & Silen, 1995).

In summary, the construction industry has been experiencing problems of information sharing at different phases of construction due to fragmentation of this industry. Many researchers also suggest that information technology will help to solve problems caused by fragmentation. In the following sections, related research studies and applications are discussed in order to propose an alternative approach.

2.2 Related Research Studies

Integration is suggested as the best approach to overcome difficulties caused by fragmentation of the construction industry (Anderson, 1981, Ndekugi, & McCaffer, 1988). A general term to describe such research activities is called CIC (Computer Integrated Construction). CIC can be defined as "a business process that links the project participants in a facility project into a collaborative team through all phases of a project" (Teicholz, & Fischer, 1994, p121).



Source: Hunnas, & Silen, 1995

Figure 2.1 Islands of information

There are two types of integration strategies, technical and managerial (Fischer, & Kunz, 1995). Technical integration strategy focuses on data interoperability of software applications that support different disciplines. Managerial integration strategy puts an emphasis on the collaboration between a client and various discipline specialists, and among specialists within project teams or an integrated design-build organization. In fact, it is argued that the AEC industry is not able to use IT (Information Technology) strategically yet because companies view IT as a technological issue, rather than a business issue, and thus delegate it to IT specialists (Betts, 1991). Therefore, most of the integration research has been focusing on proposing technical solutions to overcome fragmentation in the AEC industry (Howard, Levitt, Paulson, Pohl, & Tatum, 1989). However, managerial integration is an equally important aspect that is critical to the success of IT solutions (Earl 1989, Fischer, & Breuer, 1995). The main push in the AEC research community is to use IT to "integrate" different parties and phases in the project life cycle (Aplegat, 1988, Howard, Levitt, Paulson, Pohl, & Tatum, 1989). Thus it is clear that parallel advancement of technical integration and managerial integration will eventually be the way to go. In this dissertation, the focus will be on technical integration but both technical integration and managerial integration will be discussed.

2.2.1 Technical Integration

The purpose of technical integration is to solve the problem of data fragmentation. Basically there are four approaches to achieve this goal (Rezgui, Brown, Cooper, Yip, Brandon, & Kirkham, 1996). They are communication between applications, knowledge-based interfaces linking multiple applications and multiple

databases, integration through a shared project model holding all the information relating to a project according to a common infrastructure model, and integration through geometry. In the following sections, these approaches will be reviewed to find out common strategies that this research can apply.

Communication between Applications

Communication between applications resorts to the idea of a neutral data format. This has been already regarded as an alternative to the shared project model solution (Ahmad, Russell, & Abou-Zeid, 1995, Abou-Zeid, Russell, Hanna, & Park, 1995). The neutral data format allows different software systems to share data. Initial Graphics Exchanges Specifications (IGES) is an example of such a neutral data format for CAD systems.

The Initial Graphics Exchange Specification (IGES) defines a neutral data format that allows the digital exchange of information among computer-aided design (CAD) systems. CAD systems are in use today in increasing numbers for applications in all phases of the design, analysis, manufacture and testing of products. Since it is a common practice that a designer uses one type of CAD system and a contractor may use a different type of CAD system, there is a need for the capability of exchanging data digitally among all CAD systems. IGES provides a neutral definition and format for the exchange of specific data. Using IGES, a user can exchange product data models in the form of wire frame or solid representations, as well as surface representations. Applications supported by IGES include traditional engineering drawings as well as models for analysis and/or various manufacturing functions.

One such commercial product is the AutoCAD IGES Translator. The AutoCAD IGES Translator (AIT) is a separately purchased AutoCAD Development System (ADS)-based application for importing and exporting IGES files. This product supports the IGES Version 5.2 specification and is compatible with AutoCAD Release 13 and AutoSurf Release 2.1 software. Figure 2.2 shows how it works.

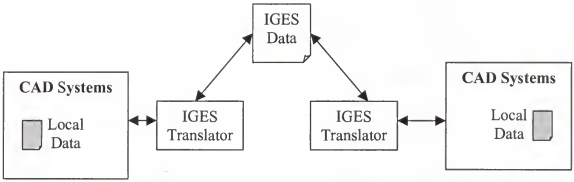


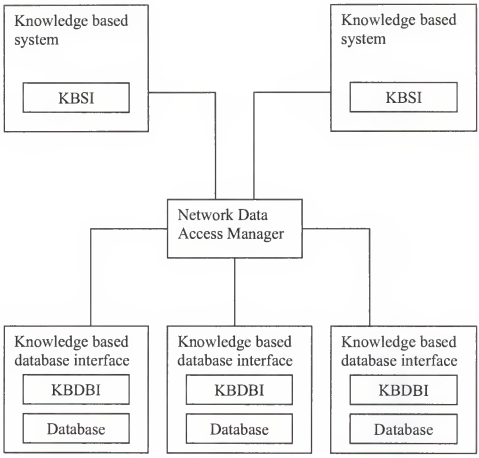
Figure 2.2 Communication through a neutral data format

Knowledge-Based Interface

This is one of the early strategies for integration. The motivation of this approach is that "production expert systems for realistic engineering applications must process large volumes of data and will require access to large distributed databases. The need to use expert systems when addressing larger problems motivated us to develop an expert system -- DBMS interface" (Howard, & Rehak, 1989, p65). KADBASSE was a classic example of such expert systems (Rehak, & Howard, 1985, 1989). The KADBASE, a knowledge based DBMS prototype, is an interface in which multiple databases and knowledge-based systems can communicate as independent, self-descriptive components within a loosely coupled distributed engineering computer system. Figure 2.3 shows an overview of the KADBASE architecture.

The KADBASE is composed of three parts, the Knowledge-Based System Interface (KBSI), the Knowledge-Based Database Interface (KBDBI) and the Network Data Access Manager (NDAM). The KBSI formulates queries and updates sent to the NDAM and processes replies from the NDAM. The KBSI possesses knowledge about the data space of the whole system and uses that knowledge to perform semantic and syntactic translations for queries, updates and replies. The KBDBI is designed for accepting queries and updates from the NDAM and returning appropriate replies. The KBDBI possesses knowledge about the local database schema and the local language for data manipulation requests. The KBDBI uses that knowledge to perform semantic and syntactic translations for queries, updates and replies. The NDAM is the actual interface between the knowledge-based system and the databases. It receives requests from knowledge-based systems (through their KBSIs) expressed in terms of the global schema. Using information associated with the global schema, the NDAM locates sources for data referenced in a request and decomposes each request into subqueries or updates to individual target databases. These subrequests are sent to corresponding KBDBIs for processing. Replies from KBDBIs are combined to form a single reply to the original request and sent to the requesting application through its KBSI.

The KADBASE is a typical example of this approach. Similarly, this type of application is applied to construction equipment management as well (Udo-Inyang, & Chen, 1997).



Source: Howard, & Rehak, 1989

Figure 2.3 The KADBASE architecture

In summary, the basic idea of the knowledge-based interface approach is that it uses knowledge systems to manipulate data that may be located in different databases and maintains a global schema to manage such data. In this way, different databases for drafting, scheduling or estimating can be integrated and data from different databases can be presented jointly.

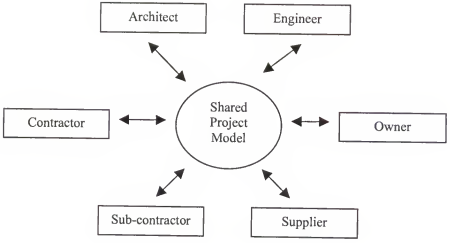
A Shared Project Information Model

The idea of a shared project information model can be traced back at least to Wright. In his paper "Computer Integrated Construction" (Wright, 1988) he discussed the idea of an integrated project information system, which he defined as a dynamic repository for project-specific information that can be appropriately accessible to all project participants. He also discussed how this idea could be implemented in the context of construction industry. He suggested that "the technologies for integrated project information systems may themselves be proprietary. Software packages and the host hardware may be commercial products. The provision of a project information service also can be a private or professional activity. The services can belong to and be operated by the owner if the owner regularly builds and operates facilities; it can be provided by the contractor or by a service bureau specializing in integrated project information system service" (Wright, 1988). Now, more than ten years later, one can see that many things that Wright "predicted" in1988 have been implemented in the construction industry.

Ever since then, the idea of the shared project information model was spinning around among the academicians. Figure 2.4 shows the typical shared project information model by project participants. This model can also be represented by different functional

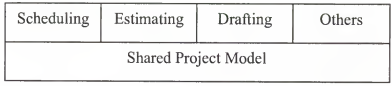
groups in the construction industry, such as designing, planning, scheduling, estimating and accounting, shown in Figure 2.5. The arrows in the diagram represent communication channels. They used to be only paper-based documents. Now paper-based documents are more and more replaced by electronic media such as disk, CD-ROM and Web pages.

One of the major advantages of the model-based approach is that a model is independent of any particular implementation and any particular application. Therefore different applications may eventually be able to share the same information model and communicate with each other via a shared information model (Rezgui, Brown, Cooper, Yip, Brandon and Kirkham, 1996). Figure 2.5 illustrates the idea of a shared project information model by applications. Examples of the model-based approach include COKE (COnstruction Knowledge Expert), OPIS (Object-model based Project Information System), ATLAS (Architectures Methodologies and Tools for Computer Integrated Large Scale Engineering), COMMIT (COMputer Models for the Building Industry in Europe), RATAS, ICON (Integration of Construction Information) and STEP (Standard for the Exchange of Product Model Data).



Source: Fischer, & Froese, 1996

Figure 2.4 The conceptual shared project information model



Source: Fischer, & Froese, 1996

Figure 2.5 Shared project model

One of achievements in this area is the IFC (Industrial Foundation Classes) by IAI (International Alliance for Interoperability). Providing a foundation for the shared project model, IFC serves as an industrial standard for the ACE/FM industry. There are three possible ways to share data using IFC (Wix, & See, 1999).

- By creating a physical file of information that may be shared across a network, by email or on a physical medium such as a floppy disk. Presently, most software applications share information using physical files.
- By placing information in a database that has an interface defined according to the ISO 10303 part 22 (Standard Data Access Interface) for putting in and getting out data. A number of software applications are using this approach at present.
- By using software interfaces that can expose the information content of defined groups of attributes within an object. Software interfaces allow for direct communication between applications without the need for an intermediate file or database.

Integration through Geometry

Since this is often the case in CAD packages where integration is based on and only limited to geometrical information (Rezgui, Brown, Cooper, Yip, Brandon and Kirkham, 1996), this type of integration will not be elaborated here.

Summary of Technical Integration

It is clear that the technical integration approaches discussed above can be generalized into two categories. One category represented by the knowledge-based interface approach features that different systems share information at a low system level. The second category represented by communication between applications does not require different systems sharing anything at system level. Instead, different systems communicate with each other through a third party. Although according to different implementations the shared project information model approach can fall into both categories, those implementations don't represent any new category.

Philosophically, such generalization about technical integration is reasonable because the problem is similar to human communication using two different languages. If two people need to communicate and they speak different languages, they either find a translator or learn to use a common language. The communication between two computer systems is a similar problem in this sense.

Furthermore, in this research, the approach of the first category, i.e. the shared project information model approach (using database and using programming interfaces) and the knowledge-based interface, is called "back-end" integration. It is called "back-end" integration because the integration actually happens at a low system level and applications are simply different views to the same database. For example, COMMIT,

ICON, and RATAS are implemented in such a way so that data and information generated within the same package do not have the data fragmentation problem at all. The second type is called "front-end" integration since integration happens at the "front" of different system that do not share anything at the system level. "Front-end" integration is based on sharing a neutral data format that is independent of any system.

2.2.2 Managerial Integration

As discussed earlier, managerial integration is as important as technical integration. Currently managerial integration is focused on using technology, such as email, EDI, conferencing tools and so on to bring project participants together (Anumba, & Evbuomwan, 1997). Technically, managerial integration is intensively and extensively under the subject of Computer Supported Collaborative Work (CSCW). The construction industry is starting to pick up this technology to support its business and operation.

More than ten years ago, Paul Cashman and Irene Grief organized a workshop of people from various disciplines who shared an interest in how people work, with an eye to understanding how technology could support them. They coined the term "Computer-Supported Cooperative Work" to describe this common interest.

In 1997, Collaboration Strategies™ conducted research to examine how large companies are using IP networks (internet protocol, i.e. internet and intranets) to support electronic collaboration. Out of 100 interviews, 85% of those interviewed responded that the internet-based collaboration is critical to the functions of their business (electronic collaboration on the internet and intranets, 1997). Among them 56% felt that collaboration was necessary to support a distributed workforce by increasing communication, coordination, facilitation and planning. It seems that the CSCW and the

problems that this technology tries to solve decide that the internet will play a significant role.

Actually the internet and intranets related CSCW applications, especially the Web-related applications, are one of the major concerns of CSCW research. Typical Web-related CSCW applications includes collaborative agent approaches (Jin, & Ohira, 1996, McGraw, Lawrence, Morton, & Heckel, 1996, Knapik, & Johnson, 1998), shared work-space approaches and work flow approaches, i.e. Alliance (Salcedo, & Decouchant, 1997), BSCW (Bentley, Horstmann, & Trevor, 1997) and WebFlow (Grasso, Menunier, Pagani, & Pareschi, 1997).

Typical research studies in the construction industry include the virtual engineering team (Line, 1997), collaborative environment for resolving conflicts and disputes due to the complexity of large-scale project construction (Pena-Mora, & Wang, 1998), collaborative system for managing design changes (Mokhtar, Bedard, & Fazio, 1998), collaborative engineering for project field inspection (Rojas, 1997) and so on.

2.2.3 A Missing Piece between the Technical Integration and the Managerial Integration

If technical integration is regarded as a tool to deal with data and managerial integration as another tool to deal with people, there is still a gap between the data and the people who use the data. The gap is how the data can be accessed. This is not an active research area because most companies simply use standard documents for storing, retrieving and disseminating data and information. Even electronically, the gap is filled by different kinds of electronic documents that are very much similar in format to their paper-based counterparts. However, if documents are treated as ways for access to other

related information rather than final presentations of data and information, there are more things to do with the documents.

To understand what else can be done with documents, we should take a look at how documents are used and what purpose they serve during project construction. During the construction phase, information is shared and disseminated through multiple bi-directional communication channels (O'Brien, & Al-Soufi, 1993, Fischer, & Kunz, 1995, Andrew, & Teicholz, 1996, Tierfelder, Webollek, WillenBacher, & Grosche, 1997). The media are different kinds of documents, which are produced, stored and used at separate locations, such as change orders, shop drawings, payroll reports, invoice and so on (Abou-Aeid, Russell, Hanna, & Park, 1995, Ahmad, Russell, & Abou-Zeid, 1995, Edwards, Shaw, & Holt, 1996, Finch, Flanagan, & March, 1996). According to a survey (Edwards, Shaw, & Holt, 1996), as much as 80% of corporate information is processed through documents. It has also been estimated that the total number of documents that relate to a single building structure may typically be in the order of 10,000 (Turk, & Bjork, 1994). Consequently it is obvious that the construction process demands timely project documentation that can be easily assimilated. Failure to effectively locate and manage documents during a project may result in delay and incorrect decisions (Finch, Flanagan, & March, 1996).

Obviously, the documents are the "things" that are actually shared by different project participants and are also gateways to the shared or non-shared project information sources. Unfortunately, not much integration research addresses how construction documents should be treated in this context.

As we know documents are "windows" to the whole process and can evolve as the process does. No matter whether they are paper-based documents or electronically generated documents, "documents are interfaces, used to access and navigate through collections of information" (Haimes, B.,1994, p.16). If we look at the whole information source of a project as a reservoir of small information objects, documents provide a way to show the viewer the semantics of the information objects and the relationships between the objects. The conventional documents only offer "separated windows" to viewers, which means it relies on viewers to combine information acquired from the "separated windows" and generate new knowledge that are not shown by the "separated windows." The "separated window" is the result of not fully using the capacity of the computer, since the computer as a mediator has the ability "to process and to alter human messages and to draw new conclusions regarding human messages" (Chesebro, & Bonsall, 1989, p. 31). The conventional documents are "fixed windows" as well. The perspective from which the information objects and their relationships are viewed is pre-set and fixed by the producers of the documents. However, very often viewers need to look at the information from another perspective based on the viewers' goals or objectives. Unfortunately, the conventional documents are not user-centered and do not allow viewers to adjust perspectives for their best understanding without other intermediary processes.

In a word, the missing piece is the construction document that needs to be more flexible to user's needs. Furthermore, since it is also a bridge between different systems and a gateway to different information sources, the construction document can be an ideal core to build a new integration strategy around.

2.3 Current Web-Based Applications in the Construction Industry

The Word Wide Web has taken the AEC (architecture engineering construction) industry by storm. Although it is still hard to predict how it will grow over the next few decades, the Web-based technology certainly exerts great influence on the AEC industry. A three-year study (Cox, 1996 & 1998, Cox, & Hampson, 1998) shows that the improvement of the internet/Web related computer capabilities reported by project managers in the USA has increased significantly, shown in Table 2.1.

Table 2.1 Average computer capabilities reported by project managers

	1996	*1997*	*1998*	*Average Rate of Increase*
Email		2.9	3.4	40%
Internet	1.8	2.6	3.1	72%
MS Word	2.8	3.5	3.5	25%
Excel	2.8	3.5	3.5	25%
L-Notes	1.7	3.1	3.1	82%
Timberline	1.5	1.5	1.9	27%
P-3	2.1	2.1	2.3	10%
ACAD	1.8	1.5	1.4	-22%

Source: Cox, 1996 & 1998, Cox and Hampson, 1998

Table2.1 shows that the use of email and the internet has increased significantly when compared with the specialized software such as Primavera Project Planning (P3), Timberline and general-purpose software such as MS Word and Excel. In reality, the internet and the Web-related technologies penetrated into the daily operation of project construction in the early and mid 90s (Wright, 1993, Setzer, 1994, Angelo, 1995, Schriener, 1995a, b, & c, Shearer, 1995).

2.3.1 Major Application Types

Ever since the internet and the Web have become accessible to the public in the early 90s, industries and academic institutions have embraced the technology quickly and

enthusiastically. After almost a decade of evolvement, three types of Web-based applications exist for the construction industry. They are "fee-based project management service," "build it yourself solutions" and "Web-enabled software." These applications share the same objective, which is to integrate the Web-based technology into project construction. They are referred to generally as project Website approaches in this research.

Fee-Based Project Management Service

This type of application is relatively new to the construction industry. However, theoretical research has already predicted the emergence of such service in the construction industry (Betts, Cher, Mathur, & Ofori, 1991, Ahmad, Russell, & Abou-Zeid, 1995, Paulson, 1995). The "Fee-Based Project Management Service" is for companies that are unwilling or unable to maintain their extranets. There are many such service providers for example e-Builder™, e-Project, Emerging Solutions (ADVANTAGENET), BlueLine/OnLine (ProjectNet), EVOLV (ProjectCenter), ThePigeonHole Inc. (ThePigeonHole), Cubus Corp. (Reviewlt AEC), and Bid-Com (BidCom).

Build It Yourself Solutions

Some AEC companies opt to develop their own Web-based project management sites. For example, engineering/construction firm, Black & Veatch, was piloting the Aspects Project Server and SiteBuilder collaborative software by Framework Technologies Corporation. Built specially for the AEC community, SiteBuilder lets users create and update project web sites while Project Server delivers collaboration and coordination functionality for project team members. Another example is a software

package developed by a general contractor, Vratsinas Construction Company (VCC). VCC has developed a project management system based on Lotus-Notes. The system helps professionals at job sites to keep track of every detail of daily construction operations. A similar system has also been developed by Zimmer Gunsul Frasca (ZGF), a Portland based company. Although the overall computing, communication and collaboration environment is improved greatly by deploying such systems, the "Build It Yourself Solutions" requires lots of commitments that may not be a good idea for many construction companies (Information Technology, the Internet and You, ENR, June, 1998). Nevertheless, some companies such as VCC prefer this kind of solution because it allows them to build applications that fit well into their own business environment and maintain their own business style.

Web-Enabled Software

Companies such as Emerging Solutions Inc. and Blue-Line/On-Line not only provide information management services but also sell their products to allow construction companies to maintain their own project Web sites. One of the advantages for companies administrating their own project Web sites is that they do not need to outsource information. This type of application is especially good for those companies who are very careful about letting other service companies control their data and information. The disadvantage is that initial cost is relative high.

In addition, an increasing number of software tools for estimating, scheduling, drafting and project management are offering Web ready features. This means that from within a specific program, the user can access and share information.

Comparison of the Three Types of Applications

The differences between the above three types of applications are very obvious. They can be simply distinguished by who built the tool and who administered the data.

The major common grounds of these software tools in terms of construction operations supported are that they all focus on establishing an on-line environment in which project participants can share information via document exchange. Typical documents that those systems supports include

- Correspondence
- Daily Report
- RFIs
- Transmittals
- Submittals
- Meeting minutes
- Document Logs
- Various reports
- Change Orders
- Purchase Orders

To understand how these Web-based applications deal with construction documents and work with other software tools such as drafting, scheduling and estimating, phone interviews and a Web search were conducted. The objective was to find answers two questions:

- Question 1: If there is an RFI (Request for Information) from a third party application, can your system automatically retrieve information from sources both within and outside your computing environment?
- Question 2: How will your system deal with other software tools such as AutoCAD, P3 and Timberline?

The results are shown in Table 2.2.

Table 2.2 A comparison of some of the major tools

	Question 1	Question 2
AdvantageNet Emerging Solutions Inc.	No. Manual retrieval	Build-in Scheduling Features. Plug-ins to other tools
ActiveProject Framework Technologies	No. Manual retrieval	Plug--ins to other tools
e-Builder™ MP Interactive Corp	No. Manual retrieval	Plug-ins to other tools
e-Project AEC Online Inc.	No. Manual retrieval	Plug-ins to other tools
ProjectCenter Evolv Inc.	No. Manual retrieval	Plug-ins to other tools
ProjectNet Blue-Line/On-Line Inc.	No. Manual retrieval	Plug-ins to other tools
ProjectWise WorkPlace System Solutions	No. Manual retrieval	Plug-ins to other tools

As shown in Table 2.2, most of the current Web-based applications are using plug-ins to work with other software tools and they also tend to work with particular software tools rather than use vendor independent solutions.

2.3.2 Limitations of the Current Web-Based Applications

One of the advantages of using the Web is that data or information can be exchanged much more quickly and efficiently. However, the construction software market has already been well structured and dominated by many well-known brands and

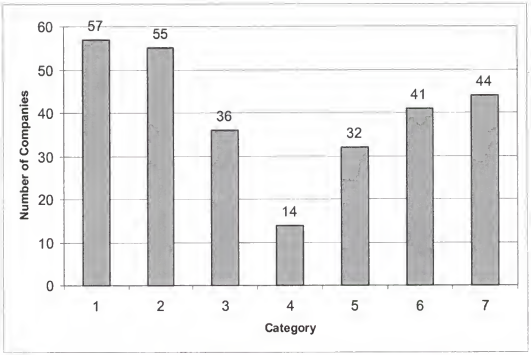
numerous small companies. It is very unlikely that one company is able to dominate the whole market; therefore, establishing a standard for document exchange over the Web is extremely important.

Table 2.3 shows some major categories of construction drafting and management software companies and illustrates the large number of players in this market. Figure 2.6 shows the number of software tools by each of the major vendors in each category. Table 2.4 shows the major vendors in each of the categories. Data and information are obtained from "A/E/C Systems The Magazine of Computer Solutions," autumn 1998.

Figure 2.6 and Table 2.4 may not illustrate the whole picture of the real world because a lot companies and products may not have been included in the magazine. The numbers and the tables simply try to show the idea that the construction related software market has been fragmented by a large number of well-established companies. Therefore it will be very unusual if one of them will be able to enter into all other AEC areas and provide a software package that includes all kinds of applications. As long as no software vendor can monopolize the whole AEC market, there is a chance that user software tools may not be compatible.

Table 2.3 Categories of software companies

Category	Meaning
1	CAD
2	Bidding, Estimating & Job Costing
3	Construction Management
4	Communication Networking
5	Financial & Accounting & Marketing
6	Engineering Document Management
7	Scheduling & Budgeting



Source: A/E/C Systems The Magazine of Computer Solutions, Autumn 1998

Figure 2.6 Number of software companies in each category

Table 2.4 Major developers in each of the major categories

Software Tools	Major Developers
CAD	Argos Systems, IncAutodesk, Inc., Bentley System, Inc., Building Blocks, Inc. , CADMAX Corp, DataCAD LLC
Bidding, Estimating & Job Costing	Bidtek, Building Systems Design, Inc., Computer Guidance Corp., Construction Data Control, Inc., Dexter + Chaney, Grantlun Corp., ICARUS, Management Computer Controls, Inc., McCosker Corp., Meridian Project Systems, Inc. , Prosoft Inc., The American Contractor, The Construction Link, Inc., Timberline Software Corp.
Construction Management	Construction Data Control, Inc., Computer Guidance Corp.,, J.D. Edwards World Solutions Co., Management Computer Control, Inc., Merdian Project System, Inc, Shaker Computer & Management Service, Inc.
Communication Networking	AEC Online, Inc., Blue-Line/On-Line Inc., Emerging Solutions, Inc., Framework Technologies, MP Interactive Corp.
Financial & Accounting & Marketing	Bidtek, Dexter + Chaney, Deltek Systems, Inc. McCosker Corp, Shaker Computer & Management Services, Inc., Solomon Software, Inc., Timberline Software Corp., The American Contractor
Engineering Document Management	ACS Software, Inc., Altris Software, CYCO Intl. Computerized Facility Integration, Inc., NMT Corp
Scheduling & Budgeting	AEC Software, Inc., Data-Maxx Software System, Inc., Emerging Solutions, Inc., Gcon, Inc., The Paragon Co., Primavera Systems, Inc.

Source: A/E/C Systems The Magazine of Computer Solutions, Autumn 1998

Put into the context discussed above, one of the limitations of the current project management Web site approach is that most systems do not effectively solve the data interoperability issue (See Table 2.2). Since different vendors may use different data models, automation of document processing is still impossible even if everybody is on the Web. For example, to process construction documents, a construction professional usually needs to use non-shared project information as well. The non-shared project information is often stored at least logically in different sources. Most of the current project Web site approaches cannot handle this situation (see Table 2.2). Thus in this case, the information fragmentation still exists because of the different locations of the shared and the non-shared project information. In this research, the non-shared source is also referred to as a local information source. Figure 2.7 shows the existence of such fragmentation.

From Figure 2.7, one can see that once a document is received via the Internet and opened by a Web browser, that document cannot be used directly to retrieve information in the local information sources because the document received may be prepared by another third-party system. Thus, in many cases, the document viewer has to manually interpret the document and then go to local information system to retrieve related information. This extra process is caused by the gap between the document prepared by the third party application and the local information as shown in Figure 2.7.

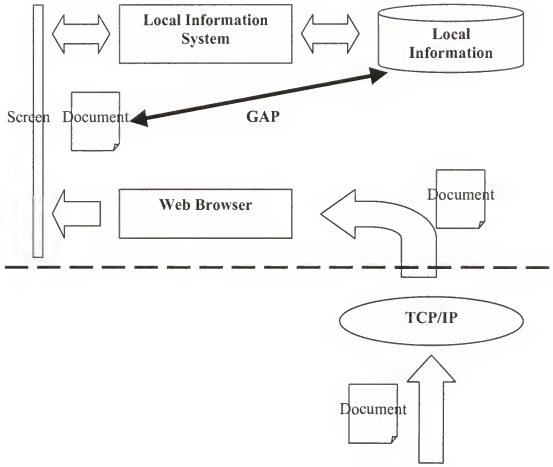


Figure 2.7 The existence of information fragmentation in the project specific Web site systems

2.4 An Alternative Solution--Web-Based "Front-End" Integration

Based on the above discussion, it seems that an alternative strategy can be achieved by focusing on two things, namely construction documents and "front-end" integration, over the Web. Construction documents are not only the media for presentation of construction information but also bridges for communication between construction participants. Effective management of project documents is critical to the success of any construction project. It is important to notice here that as far as integration is concerned construction documents should be an integral part of the whole integration strategy. Moreover, the use of construction documents as the core around which the new integration strategy can be built will naturally lead to "front-end" integration. By doing so, the alternative approach uses system-independent and vendor-independent neutral information models at the "front-end" (at the input/output level). By using this alternative strategy, it is possible to provide construction professionals with a more integrated computing environment that the current project specific Web site approach cannot. This alternative strategy is called Web-based "front-end" integration. Figure 2.8 shows the concept of the Web-based "front-end" integration.

Comparing the difference between Figure 2.7 and Figure 2.8, it is apparent that the system shown in Figure 2.8 has an additional piece dealing with the document and related local information before the document is shown to a user in a Web browser. This additional piece, called a "malleable frame," makes a construction document adjustable according to the user's needs. Any system with a "malleable frame" will be called a

"malleable frame" system. The "malleable frame" is actually what the Web-based "front-end" integration is all about.

2.4.1 A "Malleable Frame"

A "malleable frame" is a dynamic document template. Such a template will define a generic structure of a particular type of documents so that document instances can be generated according to different situations. In the Web environment, a "malleable frame" differs from a traditional document representation in such a way that the components of the documents are organized and represented in forms of various information objects that are active, interactive and standardized. In other words, those information objects are operable by different systems. For example, a change order may have information objects such as the initiator(s), the recipient(s), the contents, the signatures, etc. To be operable by different systems, the semantics of those information objects are known to all involved computer systems so that they are able to respond directly to users' interactions no matter where the systems are. For example, if a change order received changes the size of a door, the content object of this change order may only have some text about "XXX door," which is static. However, the "malleable frame" has the capability of understanding the text "XXX door" appearing on this change order and relating it to all other information objects related to this "XXX door" such as its drawings, its cost information, its material information and so on. In this way, the user can manipulate objects of a document effectively.

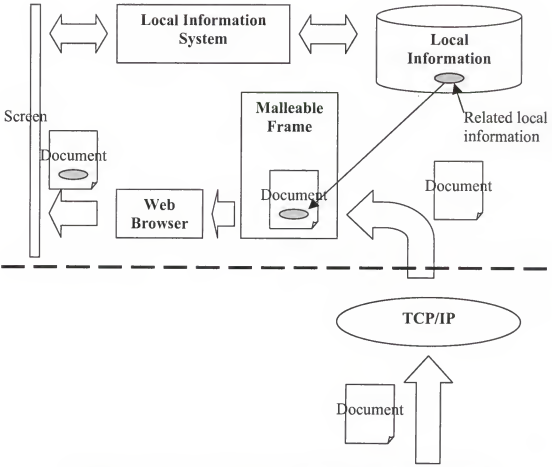


Figure 2.8 The concept of the Web-based "front-end" integration

Such a dynamic document template has already existed in PC systems where the computing environment is relative closed. In the Web environment, such a template has to be standardized in terms of object semantics and it has to be system independent as well so that a document instance generated by the template can be portable to another system. Therefore such a template can also be regarded as a neutral document format.

2.4.2 A "Malleable Frame" System

Any system that incorporates a "malleable frame" to generate document instances and interpret document instances is called a "malleable frame" system. There are two types of malleability that a "malleable frame" system supports, namely vertical malleability and horizontal malleability. Vertical malleability exists when a document flows from one stage to the next stage i.e. a stage transition, the information objects contained in the document are evolving and are getting re-organized. Vertical malleability supports this change by automatically identifying, changing, managing and juxtaposing information objects for the next stage. Horizontal malleability means that information objects of a document can be used directly by users in order to produce other information objects for the document of the next stage. For any document processing, vertical malleability and horizontal malleability are complementary to each other.

2.4.3 Characteristics of the Web-Based "Front-End" Integration

Data Granularity

A "malleable frame" is based on the idea that it is more efficient and more flexible if information can be accessed at a lower level of data granularity than the level of a document. Traditionally, construction information is shared and accessed at the level

of a whole document rather than any level with smaller data granularity. This method of sharing and accessing construction information results in some inconvenience when the document user's real interests may be in the integration of pieces of information from two or more documents. A better way is to look at a document from a different perspective. If we look at a document as a container of different kinds of information objects, the conventional documents can be generated dynamically in a real-time fashion by those information objects. For example, a request for change order proposal (RCOP) is composed of information objects such as the document title, the sender(s), the recipient(s), the date, the content of document, attachments, and signatures. The change order proposal (COP) contains additional information about pricing and scheduling while most information objects remain the same as in the RCOP. Thus if the sharing occurs at the information object level rather than the document, many information objects contained in the RCOP and the COP such as the sender(s) can be reused to generate RCOP or COP. Such reusability also indicates a low semantic level, meaning a system is now able to understand each information object.

Effectiveness and Efficiency of Information Perception

The "malleable frame" is also based on the idea that if information can be presented in a way that a viewer can easily relate the information to his or her knowledge, experience, background and so on, the information can be understood more easily.

As construction work progresses, as-built information is generated and stockpiled. All information, as-designed information, as-built information, non-shared or any of the combinations, is referenced frequently by different participants to support their decision-

making processes. The incentive for reference is triggered when uncertainty rises (Weaver, 1949, Littlejoin, 1983, D'Ambra, & Rice, 1994, Cragan, & Shields, 1998), or there is simply lack of information since information is a measure of uncertainty. In other words, information is the number of messages required to completely reduce the uncertainty in the situation (Littlejohn, 1983). One of the reasons that uncertainty may rise is because project participants have different goals (Hendrickson, & Tung, 1989 and Barrie, & Paulson, 1992) and the as-designed, as-built, or non-shared information may not quite explain the alternatives to achieve their goals. So the project participants will need extra information that may be from private sources or other sources.

The process to reduce the uncertainty is a series of interactive communication, according to uncertainty reduction theory (URT) (Cragan, & Shields, 1998). The communication can be between two people, or people and information sources. The uncertainty is likely to be reduced more quickly if the information represented can be related to a person's previous experience, knowledge, or expertise (Littlejoin, 1983, Devite, 1985).

We can also look at the problem from another point of view, the "purposeful state" theory (Ackoff, 1972). Information has three levels, the technical level, the semantic level and the effectiveness level (Weaver, 1949). At the effective level, "communication via message affects the system if it changes the 'purposeful state' of the organism" (Littlejoin, 1983, p. 24). In other words, information may not be effective if it does not support people to determine an alternative to their goals. Therefore, if information from project information sources cannot support a participant's specific goal, that information is not effective in this case. Since construction documents are containers

and gateways of project information, one way to reduce that possibility of ineffectiveness is to make construction documents as malleable as possible to support the goals of different project participants.

A Web-Based Approach

Faster information dissemination requires a better communication infrastructure. Many studies and applications suggest using the Web as a medium to disseminate information (Bentley, Horstmann, & Trevor, 1997, Bradbury, 1998, Walch, Leo, & Antevy, 1998). The method of using the Web as a medium is not new to the construction industry (Schriener, 1995a, b, & c, Turk, 1995, Fruchter, & Reiner, 1996, Liu, Stumpf, & Chin, 1996, Brideges, 1997, Rojas, 1997). There are a number of compelling reasons to use the Web as a communication medium (Lynch, 1996), one of which is that the Web is a standard computing platform that is an ideal tool for the integration of data from different systems.

2.5 Summary

Fragmentation of the construction industry in terms of the industry structure and the construction process has been studied for a long time. Its negative effects on electronic data exchange and electronic construction document management have also been noticed and studied under the umbrella of CIC (Computer Integrated Construction).

Integration has been suggested as a way to overcome fragmentation. There are two types of integration, technical and managerial. It is noticed that there is another layer between technical integration and managerial integration, which is how data can be effectively and efficiently accessed. In the construction industry, project participants rely

heavily on construction documents to get information. This indicates that construction documents can be a focus of an alternative integration solution.

Technical integration has two strategies. One is that different systems share a common model or common knowledge at low system level, which is called "back-end" integration. The shared project information model approach that is implemented by a shared database is a typical example. The other strategy, which can be called "front-end," is that different systems communicate through a common or neutral data format. They may not share anything at the low system level. An example of such strategy is the IGES (Initial Graphics Exchanges Specifications) translator.

In practice, the current project specific Web site approach with three different types does not support integration of different software tools. This limitation greatly discounts the advantages of Web-based applications since the Web is designed for improving data interoperability.

Based on the context discussed above, an alternative integration strategy is proposed. Relying on a "malleable frame" and accordingly a "malleable frame" system, the alternative strategy focuses on applying the "front-end" integration to Web-based construction documents. The following chapters will discuss details on building a "malleable frame" and a "malleable frame" system, and testing the hypothesis.

CHAPTER 3
DEVELOPMENTOF A "MALLEABLE FRAME"

A "malleable frame" is basically the neutral format of a construction document. In the Web environment, such a neutral format can be designed by using XML (eXtended Markup Language) technology. Although it is not required by XML, a DTD (Document Type Definition) is normally used to define the structure and tags of a document. With a DTD, a certain type of document is thus defined. This chapter will discuss how to develop such a neutral format for a Request for Change Order Proposal by using SGML (Standard Generalized Markup Language) and XML technology.

3.1 A Brief Introduction to SGML and XML

3.1.1 SGML(Standard Generalized Markup Language)

SGML, Standard Generalized Markup Language, is an international information coding standard. In 1978, an ANSI (American National Standards Institute) working group (X3 J6) was formed to provide an unambiguous format for text interchange and a markup language that would be sufficiently rich to permit any processing. In the early 80s this work was moved to ISO under a working group which is part of SC18 (ISO/IECJTC1/SC18/WG8) whose work later resulted in the SGML standard (Van Herwijnen, 1994).

One of the major advantages of SGML is the separation of document structure and document layout. This advantage eventually makes SGML document portable among different systems.

SGML uses tags to define information contained in a document. There are three types of tagging schemas, namely format tagging, structure tagging, and content tagging. HTML (Hypertext Markup Language) and XML apply format tagging and content tagging respectively.

SGML has developed some formal methods for developing DTDs. This research will use those methods to develop a DTD for the Request for Change Order Proposal.

3.1.2 XML (eXtened Markup Language)

Currently, most documents on the Web are stored and transmitted in HTML. As mentioned previously, HTML is a sub-set of SGML (Standard Generalized Markup Language) and its tags are for presentation purposes mainly. This makes HTML a simple language that is well suited for hypertext, multimedia, and the display of text documents. However, the limitations of HTML become obvious as well, where the semantics of a document's content is concerned. Major limitations are extensibility, structure and validation (Bosak, 1997, Microsoft Corporation, XML White Paper, 1998). The limitations may now be removed by a new meta-language, XML, which was designed by the W3C (World Wide Web Consortium) as the next generation open data format for the Internet.

XML provides two major services. One is the syntax for document markup and the other is the syntax for declaring document structure (St. Laurent, 1998). Such services provide software developers with a neutral layer, or a neutral data format, that

can glue together heterogeneous data and applications, and provide end users with a much richer set of Web applications for browsing, communication and collaboration.

Instead of focusing on the presentation of information like HTML does, XML focuses on the semantics of information that is displayed, and separates the content of a document from its presentation (St. Laurent, 1998, Microsoft Corporation, XML White Paper, 1998, Sall, 1997). In this way, XML provides more user-friendly applications by allowing users to tailor presentations according to their needs. This research will only review certain topics that are related to this application. For details about those specifications, please visit the W3C Web site at http://www.w3c.org/.

XML Specifications

Formally, XML has three specifications (Sall, 1997), XML 1.0, XML linking language and XML style language (XSL). However, several other specifications related to XML activities are proposed and recommended as well, such as the Document Object Model (DOM) specification, XML namespaces, resource description framework (RDF), XML data and XML vocabularies. Many of the specifications are still under development. As of writing, the XML 1.0 and the DOM (recommended) are available. The XML linking language and the XML style language are still at the working draft stage and the proposal stage respectively.

XML Syntax

XML uses an EBNF (Extend Backus-Naur Form) syntax (XML Specification, 1997). An example of the syntax for the element's content is as follows:

```
content ::= (element | CharData | Reference | CDSect | PI | Comment)*
```

Figure 3.1 A sample of XML syntax

XML Document Markup

XML is a subset of SGML therefore the document markup is similar to SGML. The purpose of the XML markup is to provide a universal method for describing data. There are six kinds of markup that can occur in an XML document (XML Specification, 1997, Walsh, 1997): elements, entity reference, comments, processing instructions, marked sections and document type declarations. Following are explanations of those types of markup.

Elements. Elements are the most common form of markup. They are delimited by angle brackets and in most cases used for identifying the nature of the content they surround. Some elements may be empty in which case they have no content. If an element is not empty, it begins with a start-tag, <element>, and ends with an end-tag, </element>.

Elements may have attributes. Attributes are name-value pairs occurring inside tags after the element name, e.g. <projectDocument type="project manual">. In this example, a projectDocument element has an attribute of "type" with its value assigned to "project manual."

Entity Reference. Some special characters such as "<" are reserved for markup. In order to be able to use them in a document as content, there must be alternative ways to represent them. In XML, entities are used to represent those special characters.

Comments. Comments in XML begin with "<!--" and end with "-- >". Comments can contain any data except the literal string "--".

Processing Instructions. Processing Instructions (PIs) are an escape hatch to provide information to an application. They have the form: <?name pidata?>. The name, called the PI target, identifies the PI to the application. In XML, the name is "XML". The pidata is optional, such as "version="1.0"".

CDATA Sections. A CDATA section instructs a XML parser to ignore most of the markup characters. This is used when the content of a document contains some special characters such as "<". A XML parser will otherwise generate errors. A CDATA section takes a form: <![CDATA[content]]>. The only string that is not allowed in the CDATA section is "]]>".

Document Declarations. Document declarations allow a document to communicate meta-information to the parser about its content. Meta-information includes the allowed sequence and nesting of tags, attribute values and their types and defaults, the names of external files that may be referenced and whether or not they contain XML, the formats of some external (non-XML) data that may be included, and entities that may be encountered. There are four types of declarations in XML (XML Specification, 1997, Walsh, 1997): element declarations, attribute list declarations, entity declarations, and notation declarations. For example, an example of element declarations is shown in Figure 3.2. Element declarations identify the names of elements and the nature of their element.

```
<!Element workitem (description+, attachment, reference?)>
<!Element description (#PCDATA|type)*>
```

Figure 3.2 A sample of element declaration

A document declaration is mainly to tell the XML parser the structure of a document. An XML document is valid, which means a document type definition (DTD) is associated, or be well formed, which means a DTD is not required and the document obeys the XML syntax (Sall, 1997, XML Specification, 1997, Walsh, 1997). The structural information of documents are therefore explicitly declared by DTDs (Document Type Definition) or implicitly declared by documents themselves (a well-formed document).

3.2 A Sample Construction Document

3.2.1 Construction Change Order and Change Order Processing

Without change orders, most projects could not be timely and efficiently completed. Changes can occur for many reasons that include the followings (Mincks, & Johnston, 1998):

- Owner directed change of scope. Extra work is added to or deducted from the project and it is clearly a change of scope to the contract.
- Constructive change. The architect or owner representative causes the contractor to perform work outside his contract.
- Consequential change. This occurs as a consequence of the preceding two changes.
- Differing site conditions. This change applies to differing subsurface conditions than are indicated by contract documents or are available from geotechnical reports.

- Jobsite discovery of hazardous materials. This often causes work to stop.

According to different situations, changes can be made at no cost and with no change in duration, or can result in greater or less costs and require an addition or a reductionin contract time.

The whole change order process consists of several steps, one of the important steps for contractors is to return a change order proposal. Figure 3.3 shows the information flow of this step.

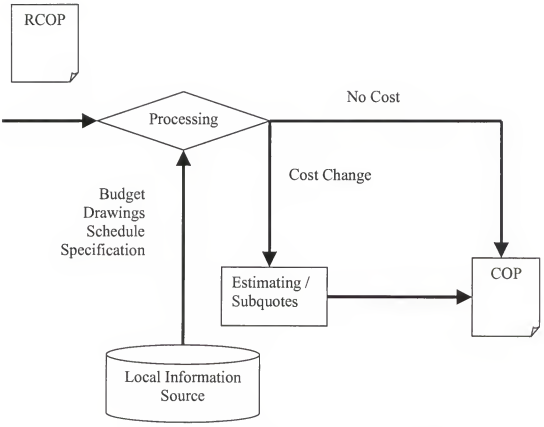


Figure 3.3 The step to produce a Change Order Proposal

3.2.2 A Request for Change Order Proposal

From Figure 3.3, one can see that quickly and efficient processing a Request for Change Order Proposal is the key. There are standard documents i.e. the American Institute of Architects (AIA) documents, the Engineers Joint Contract Document Committee (EJCDC) documents, the Construction Specification Institute (CSI) documents and the Associated General Contractors of America (AGC) documents. There are also countless customized documents by different contractors. A sample documents of "Request for Change Order Proposal" is shown in the Appendix A.

3.3 Methodology for Developing A Document Type Definition (DTD)

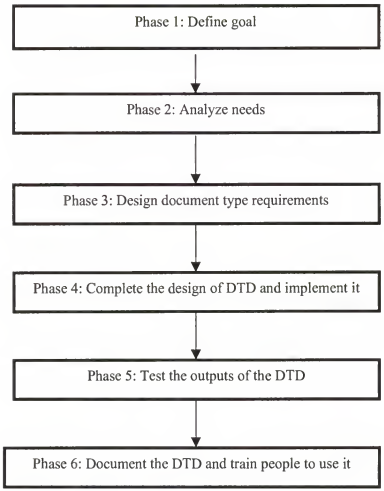
3.3.1 Phases of Development

A complete process of developing a DTD usually has several phases. Figure 3.4 shows a six-step model of developing DTD. This chapter will develop a DTD for a Request for Change Order Proposal, following phase 2, 3 and 4. The approaches used here are replicable so that other construction documents can be developed in the same way.

In this chapter, phase 2 and 3 will be discussed in detail to develop a DTD for a request for change order proposal.

Phase 2 normally includes three steps:

1. Identify and define the basic information elements that markup must encode
2. Classify the elements into logical groups
3. Validate the analysis against other models that have already been developed



Source: Maler, & Andaloussi, 1996

Figure 3.4 Phases for developing DTD

Construction documents have already been well studied, formatted and standardized, therefore what need to be done are simply to collect construction document samples and classify information contained by those samples. A sample construction documents is included in Appendix A.

Based on the elements identified in Phase 2, Phase 3 will focus on building a document model. This model can be represented by one of the formal methods, i.e. the tree diagram, the railroad model and the elm tree diagram. Another issue in this phase is to define attributes of each element. Since the attribute list of each element can include almost everything, this research only focuses on attributes of some particular elements.

3.3.2 Models for Illustrating Document Structure

A key step in DTD development is to develop a document model that illustrates the structure of a document. There are many different types of developing approaches, i.e. tree diagrams, box diagrams, sample marked-up pages, railroad model diagrams, and elm tree diagrams ("elm" stands for "enables lucid models"). Tree structures, box diagrams and sample marked-up pages are used for representing instances of a model, not the model itself (Travis, & Waldt, 1995). The elm tree diagram improves the tree structure approach by incorporating SGML properties into the document structure represented as a tree. The railroad model diagram is a method to model a document generically. This research will use the railroad model diagram to develop a document model of a Request for Change Order Proposal. Suppose that there is a recipe structured as shown in Figure 3.5:

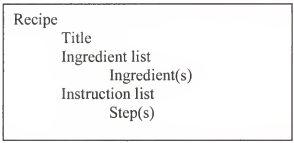
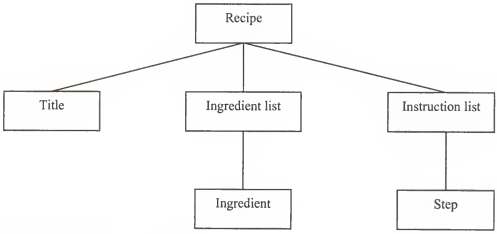


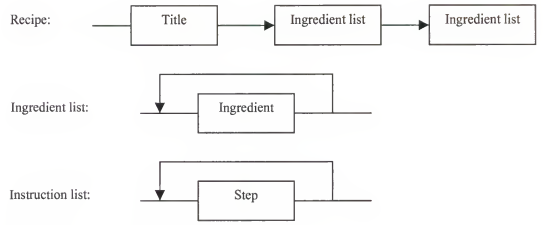
Figure 3.5 A sample structured document

The graphical representations of the structured document, three types of diagrams, the tree diagram, the railroad model and the elm tree diagram, are illustrated for comparison in Figure 3.6 - 3.8.



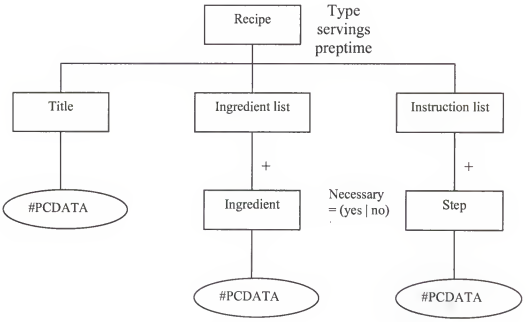
Source: Maler, & Andaloussi, 1996

Figure 3.6 A tree structure



Source: Maler, & Andaloussi, 1996

Figure 3.7 A railroad model structure

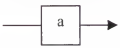
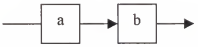
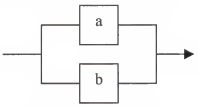
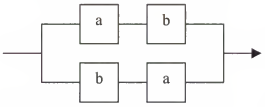
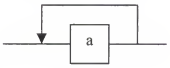
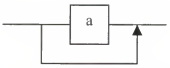
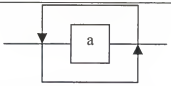


Source: Maler, & Andaloussi, 1996

Figure 3.8 A elm tree structure

3.3.3 Railroad Model Diagrams

There are seven basic structures of railroad model diagrams, see Figure 3.9.

Basic Structure	Meaning
	One element a that appears once
	One element a followed by an element b. Both appear once and a precedes b.
	One element a or one element b. Exactly one of them will appear but not both.
	One element a followed by one element b or one element b followed by one element a. This means both elements must appear in arbitrary order.
	At least one element a followed by any number of a's. In other words, a must appear at least once.
	An optional element a.
	An undetermined number of elements a

Source: Van Herwijnen, 1994

Figure 3.9 Basic structures of railroad model diagrams

A terminal element is represented with a triangle in the bottom right hand corner, as shown in Figure 3.10.

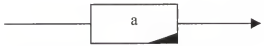


Figure 3.10 A terminal element

3.4 A DTD for A Request for Change Order Proposal

Developing a DTD for a Request for Change Order Proposal involves defining the structure of a Request for Change Order Proposal. This DTD will serve as a guideline to develop a Request for Change Order Proposal in a XML (neutral) format. Such a document in the neutral format will then be used to show the malleability of the "malleable frame" system.

3.4.1 Document Analysis

There are many samples of Request for Change Order Proposals. These samples can be standard documents or non-standard documents. Appendix A includes one sample of Request for Change Order Proposals.

However, these samples normally do not show what types of information are included in "Description". To determine that, two samples from an actual construction project are used.

Sample One: DESCRIPTION: REVISION TO DOOR AT CLOSET 4-220 Relocate door 4-221B to open to the corridor side or opposite side of the closet as shown on the attached sketch. Reverse the light switch so that it is accessible on the right hand side of the door upon entering the revised closet. The hardware, door and frame remain the same.
Sample Two: DESCRIPTION: CHILLED WATER FOR PHASE II Provide chilled water capped in the ceiling on the third floor of the new patient tower connector as requested by the GRGV's PR#M09 (note: drawing number).

Figure 3.11 Sections of construction document samples

From these two examples, it is obvious that normally the content of the "Description" should at least include

- The building component(s) involved in the document
- The other related building component(s)
- Related drawings
- Related specifications
- Descriptions about the request
- Actions expected
- Other related information

In addition the elements identified above, this research distinguishes between three types of information, i.e. project information, document information and document content. Table 3.1 shows information included in each of the types.

Table 3.1 Information typically contained in a Request for Change Order Proposal

Type	Information
Project Information	Project Name, Project Number, Contract Date, Owner (Name, Address, Phone, Fax, Web Address, etc), Architect (Name, Address, Phone, Fax, Web Address, etc)
Document Information	From, To, Document Number, Document Date, Check List (Architect, Owner, Contractor, Consultant and Other), Document Notice and Description, Signatures and Others
Document Content	Item Name, Description (main component(s), related component(s), conditions and actions), Drawings, Specifications, Others

3.4.2 A Document Model For A Request for Change Order Proposal

Using the railroad model diagram, the document model of a Request for Change Order Proposal can be represented by railroad model diagrams. Although Table 3.1 shows a summary of information contained in a Request for Change Order Proposal, it does not show the structure of the document. A railroad model diagram shows not only what information is included in the document, but also the structure of how the information is composed to form the document. Thus such a diagram is a bridge between a document and a DTD. Figure 3.11- 3.17 show the document models of a Request for Change Order Proposal (RCOP).

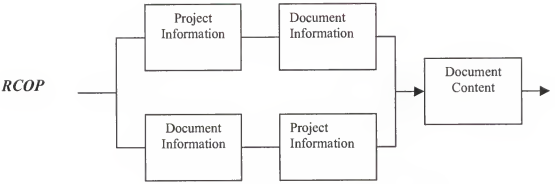


Figure 3.11 Root element of a RCOP

Project Information: (Since there are four elements, in total there will be 32 permutations to show the sequence of the elements is arbitrary. To make it simpler, the following diagram will use dot lines to represent such relationship).

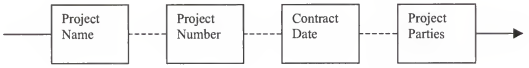
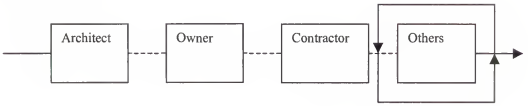
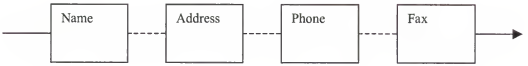


Figure 3.12 Project information element of a RCOP

Project Parties



Architect, Owner, Contractor and Others



Project Name, Project Number, Contract Date, Name, Address, Phone and Fax

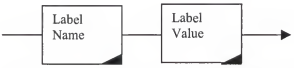


Figure 3.13 Sub-elements of project information of a RCOP

Document Information

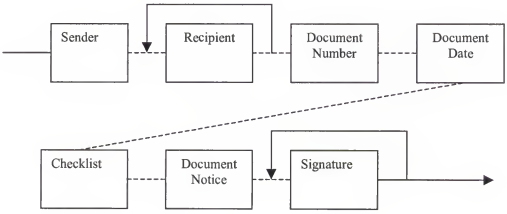


Figure 3.14 Document information element of a RCOP

Sender, Recipient, Document Number, Document Date, Document Notice, Signature, Others

Figure 3.15 Sub-elements of document information of a RCOP

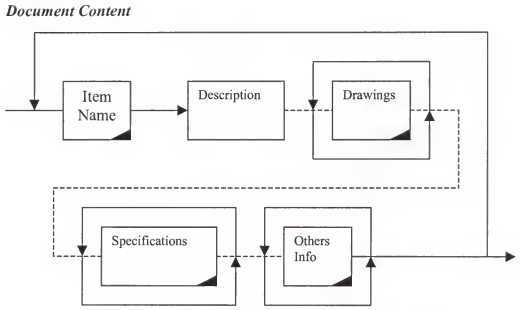


Figure 3.16 Document content element of a RCOP

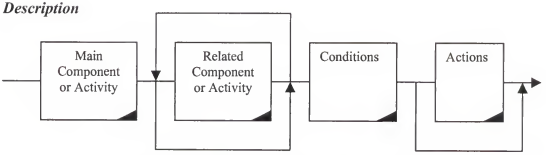


Figure 3.17 A sub-element of document content of a RCOP

3.4.3 A DTD for The Request for Change Order Proposal

With the clear definition of the structure of a Request for Change Order Proposal, this section will convert the graphic diagrams into a DTD that is shown in Figure 3.18. The meaning of some symbols used in the Figure 3.18 are explained in Table 3.2 and 3.3.

Table 3.2 Occurrence Indicators

Symbol	Meaning
(nothing)	Sequence, required, one must occur
?	Optional, zero or one can occur
+	Required and repeatable, one or more must occur
*	Optional and repeatable, zero or more may occur

Table 3.3 Connectors

Symbol	Meaning
,	Is followed by
( )	Grouping
|	Or, one of the elements in the group may occur
&	And , all must occur in any order

```
<?XML verion="1.0" ?>

<!DOCTYPE document SYSTEM "RCOP.dtd">

<!-- ELEMENT DECLARATION --->

<!ELEMENT document (projectInfo & documentInfo & documentContent) >
<!ELEMENT projectInfo (projectName & projectNumber & contractDate & projectParties)>
<!ELEMENT documentInfo (sender & recipient + & documentNumber & documentDate
                        & checklist & documentNotice & signature +)>
<!ELEMENT documentContent (itemName, description , (drawings * & specifications*
                        & others *) * ) +>
<!ELEMENT projectName (labelName, labelValue)>
<!ELEMENT projectNumber (labelName, labelValue)>
<!ELEMENT contractDate (labelName, labelValue)>
<!ELEMENT projectParties (architect &  owner & contractor  & others* )>
<!ELEMENT architect (name, address, phone, fax)>
<!ELEMENT owner (name, address, phone, fax)>
<!ELEMENT contractor (name, address, phone, fax)>
<!ELEMENT others (name, address, phone, fax)>
<!ELEMENT name (labelName, labelValue)>
<!ELEMENT address (labelName, labelValue)>
<!ELEMENT phone (labelName, labelValue)>
<!ELEMENT fax (labelName, labelValue)>
<!ELEMENT others (labelName, labelValue)>
<!ELEMENT sender (labelName, labelValue)>
<!ELEMENT recipient (labelName, labelValue)+>
<!ELEMENT documentNumber (labelName, labelValue)>
<!ELEMENT documentDate (labelName, labelValue)>
<!ELEMENT signature (labelName, labelValue+)>
<!ELEMENT checklist (cl_architect, cl_owner, cl_contract, cl_consultant, cl_other)>
<!ELEMENT cl_architect (labelName, labelValue)>
<!ELEMENT cl_owner (labelName, labelValue)>
<!ELEMENT cl_contractor (labelName, labelValue)>
<!ELEMENT cl_consultant (labelName, labelValue)>
<!ELEMENT cl_other (labelName, labelValue)>
<!ELEMENT documentNotice  (#PCDATA)>
<!ELEMENT labelName (#PCDATA)>
<!ELEMENT labelValue(#PCDATA)>
<!ELEMENT itemName (#PCDATA)>
<! ELEMENT description (mainComponent, relatedComponent *, condition, actions?)>
<!ELEMENT drawings (#PCDATA)>
<!ELEMENT specifications (#PCDATA)>
<!ELEMENT othersInfo (#PCDATA)>
<!ELEMENT mainComponent (#PCDATA)>
<!ELEMENT relatedComponent (#PCDATA)>
<!ELEMENT conditions (#PCDATA)>
<!ELEMENT actions (#PCDATA)>
```

Figure 3.18 A DTD for a Request for Change Order Proposal

```
<!-- Attribute Declaration →
<!ATTLIST document          type        CDATA       #required>
<!ATTLIST itemName          gid         ID          #required>
<!ATTLIST mainComponent
                            key         CDATA       #required
                            reference   (yes | no)  'yes'     >
<!ATTLIST relatedComponent
                            key         CDATA       #required
                                reference   (yes | no)  'yes'     >

<!ATTLIST drawings
                            key         CDATA       #required
                            attachment  (yes | no)  #implied
                            reference   (yes | no)  'yes'     >
<!ATTLIST specifications
                            key         CDATA       #required
                            attachment  (yes | no)  #implied
                            reference   (yes | no)  'yes'     >
```

Figure 3.18 Continued

This section discusses how to present a construction document in the right format, i.e. the DTD of the construction document, so that a computer can understand what the document is and what information is included in the document. Furthermore, if the DTD and the associated tags are standardized, different computer system can share the semantics of the document. However, one problem that has not yet been discussed deeply enough in this section is that how the information in the document can be used to retrieve information in a document viewer's local system. This problem will be discussed in the next chapter.

3.5 The Request for Change Order Proposal in XML Format

Based on the DTD above, the sample document for Request for Change Order Proposal can be written in XML format, which is shown in Figure 3.19.

3.6 Summary

The malleability is actually achieved by two factors, a structured document in a neutral format and a system that can interpret the document. This chapter discussed how to convert a typical construction document, a Request for Change Order Proposal, into XML format. This is achieved by using a formal method to develop a DTD of a Request for Change Order Proposal. Based on the DTD, instances of such a document can be derived. The development of the DTD in this dissertation uses a top down approach that is based on sample documents to develop document requirements. A DTD can be developed by a bottom up approach as well, by which data models such as IFC (Industrial Foundation Class) data models can be used to define objects and relationships between objects. A DTD then can be generated according to the data models.

In addition, the DTD also provides a hyperbase indicating what types of information elements are included, the hierarchy that those elements form, and what kinds of relationships exist between those elements. Such analysis will be used for developing a hypermedia system later in the next chapter.

```
<?xml version="1.0"?>
<document type="changeRequest">

<projectInfo>
        <projectName>Flagler Hospital</projectName>

        <porjectNumber>94345</projectNumber>

        <contractDate>
                <labelName>Contract Date</lableName>
                <labelValue>1998-8-12</lableValue>
        </contractDate>

        <projectParties>
                <architect>
                        <name>Albert Design</name>
                        <address>2345 NW 345 Rd., Gainesville, FL 32445</address>
                        <phone>(352)1234567</phone>
                        <fax>(352)7653432</fax>
                </architect>
                <owner>
                        <name>University of Florida</name>
                        <address>2345 NW 345 Rd., Gainesville, FL 32445</address>
                        <phone>(352)1234567</phone>
                        <fax>(352)7653432</fax>
                </owner>
                <contractor>
                        <name>Gator Construction</name>
                        <address>2346  NE 35 St, Gainesville, FL 32465</address>
                        <phone>(352)8769152</phone>
                        <fax>(352)5869435</fax>
                </contractor>
        </projectParties>
</projectInfo>

<documentInfo>
        <sender>
                <labelName>ARCHITECT</labelName>
                <labelValue>Albert Design</labelValue>
        </sender>

        <recipient>
                <labelName>CONTRACTOR</labelName>
                <labelValue>Gator Construction</labelValue>
        </recipient>
```

Figure 3.19 A Request for Change Order Proposal in XML Format

```
        <documentNumber>
                <labelName>Proposal ID</labelName>
                <labelValue>23</labelValue>
        </documentNumber>

        <documentDate>
                <labelName>Proposal Date</labelName>
                </labelValue>1998-12-1</labelValue>
        </documentDate>

        <checklist>
                <cl_architect>
                        <labelName>ARCHITECT</labelName>
                        <labelValue>Albert Design</labelValue>
                </cl_architect>
                <cl_owner>
                        <labelName>OWNER</labelName>
                        <labelValue>University of Florida</labelValue>
                </cl_owner>
                <cl_contractor>
                        <labelName>CONTRACTOR</labelName>
                        <labelValue>Gator Construction</labelValue>
                </cl_contractor>
        </checklist>

        <documentNotice>
                Please submit an itemized quotation for changes in the Contract Sum
                and/or Time incidental to proposed modifications to the Contract
                Documents described herein. All items listed below may be clarifications
                only without affecting cost or schedule.
        </documentNotice>

        <signature>xxx</signature>
</documentInfo>

<documentContent>
        <itemName gid="15_001">CHILLED WATER FOR PHASE II</itemName>
        <description>
                <mainComponent>chilled water  for phase II</mainComponent>
                <condition>
                        Provide chilled water capped in the ceiling on the third floor of the new
                        patient  tower connector as requested by the GRGV's PR#M09
                </condition>
        </description>
        <drawing>M09.gif</drawing>
</documentContent>

</document>
```

Figure 3.19 Continued

CHAPTER 4
"MALLEABLE FRAME" SYSTEM DESIGN

In Chapter 3, the development of a DTD (Document Type Definition) is discussed. Such a DTD is in fact what makes a document malleable. Serving as a generic document template a DTD defines the structure of the information elements of a document, and the semantics of those information elements, therefore if a DTD is shared by different systems, those systems will be able to interpret the same document exactly the same way. Besides, since a DTD defines each element of a document, different systems will then share the meaning of document up to the element level. That is how one system can manipulate a document prepared by another system.

Besides such a DTD, tools need to be available for users to take advantage of malleability. This chapter will concentrate on the discussion of the design of such tools, a "malleable frame" system. There are two major issues, which are the design of the system structure that has malleability and the application of a standard construction information classification system that can be used to search and retrieve local information. This research will assume that such an information classification system is available, i.e. the CSI Masterformat, to simplify the problem.

4.1 Methodologies for Developing Hypermedia Systems

A "malleable frame" system is a Web-based hypermedia system by nature therefore this section will first review some major methodologies of hypermedia design

Methodologies for hypermedia development have already been studied and well documented in the past ten years. One of the major development philosophies is the separation of design and production (Garzotto, Paolini, & Schwabe, 1993). Although not clearly discussed in the early design methodologies, "hypermedia development often faces two major tasks. One is called author-in-the-large, which focuses on the specification and the design of the global and structural aspects of a hypertext application. The other task is called author-in-the-small, which focuses on the contents of nodes" (Garzotto, Paolini, & Schwabe, 1993). The identification of the two different tasks finally leads to the separation of the specification design and the implementation. However, the two tasks are typically very interwoven. The design deliverable is not a hypermedia document but rather a specification book that is handed to a production team to be implemented. As a result, major design approaches and implementation approaches will be discussed separately as well.

The most influential examples of early hypermedia design methods are probably the g-IBIS (Conklin, & Begeman, 1988) and the Dexter Hypertext Reference Model (Halasz, & Schwartz, 1990, Halasz, & Schwartz, 1994). The early development efforts, such as the Dexter Hypertext Reference Model, tried to abstract all existing hypertext systems in order to provide a basis for description, comparison and interchange. Later approaches, such as the HDM (Hypertext Design Model) (Garzotto, Paolini, & Schwabe, 1993), the RMM (Relationship Management Methodology) (Isakowitz, Stohr, & Balasubramanian, 1995) and the OOHDM (Object-Oriented Hypertext Development Methodology) (Schwabe, Rossi, & Barbosa, 1996), have distinct characteristics. Those approaches "choose not to represent all aspects of the existing systems but instead

present a particular and logically consistent view of hypertext that satisfies a particular goal and separate design from implementation" (Garzotto, Paolini, & Schwabe, 1993, pp5). Most current application designs can find their roots from the above three approaches.

4.1.1 HDM

HDM, with a goal of supporting specification design, provides means for describing application schemas, which in turn can then be used to generate different instances. To facilitate the specification design, HDM has a set of terms and concepts called HDM primitives for describing a hypertext application. The HDM primitives and design methodology will be discussed briefly in the following.

HDM Primitives

HDM primitives include *entity*, *component*, *unit*, *perspective*, and *links*. An *entity* is a structure of information that represents some real world objects of an application domain, such as a construction document. An *entity* has an entity type, for example, "construction document" is the entity type of a construction document. One of the important characteristics of an entity is that its existence does not depend on other entities. An *entity* is a hierarchy of *components* arranged in a tree-like fashion. For example, a construction document may have "Contractor" as one of its components. A *component* in turn is made of *units*. Each *unit* is an actual container of information for the corresponding *component*. A unit is characterized by a name (its identifier) and a body. Bodies of unites are places where the actual content of an application is filled in. For example, "name/Bechtel" is one of the *units* of the *component,* "Contractor".

Usually, each *unit* shows the content of a component under a particular *perspective*. In HDM, *perspective* captures the notion of having different presentations for the same content. For example, in hypermedia applications different media, such as text, graphic, video, sound, etc., are very often used for presenting the same pieces of information. Each of those presentation methods is a particular *perspective*.

HDM has three types of links: *perspective links*, *structural links*, and *application links*. *Perspective* links connect different units that correspond to the same component. *Structural links* connect components belonging to the same entity. *Applications links* are used for applications in arbitrary patterns set up by users.

Based on above primitives, specifications of hypertext applications can be developed. A specification consists of a *schema definition* and a set *of instance definitions*. A schema definition specifies a set of entity types and link types, while instances are generated only if a set of rules or constraints is satisfied.

HDM has another important primitive called *outlines*. A hypermedia application can be roughly divided into two portions: a *hyperbase* and a *set of access structures*. What have been discussed already are primitives for defining the *hyperbases* of an application. However, to facilitate navigation, access structures are needed to allow users to properly select entry points of the application. In HDM, *outlines* are provided for this purpose.

The HDM primitives provide a conceptual model for defining any kind of hypermedia applications, while how users perceive the information is defined by *browsing semantics*.

HDM Browsing Semantics

The browsing semantics, which is application-related, defines how a hypertext is used and what information users can perceive. Since HDM defines very high level concepts of hypermedia design and does not aim at any kinds of hypermedia applications, it is impossible for it to define lots of browsing semantics except for something that is common to all hypertext designs. Thus, by default HDM only defines one type of *browsing semantics*, *nodes-and links*. In other words, the HDM default *browsing semantics* can only define *units* and *links* among *units*. This problem is not that serious when dealing with hypermedia applications, because the browsing semantics for applications is normally explicit.

The HDM primitives and other concepts will be used extensively in the following chapters.

4.1.2 OOHDM

The OOHDM is a model-based approach for hypermedia designs. Its design process consists of three different activities, conceptual design, navigational design, and abstract interface design (Schwabe, D., Rossi, G. and Barbosa, S., 1996). OOHDM is more or less influenced by HDM, therefore only major features of this methodology are briefly reviewed.

Conceptual Design

OOHDM conceptual design is a stage to develop an object-oriented model for an application domain. The result of this step is a schema built out of classes, sub-classes and relationships.

Navigational Design

The navigational design organizes views for different users and different tasks based on the conceptual design. Based on the conceptual schema, the navigational design in OOHDM has two schemas, the navigational class schema and the navigational context schema. Consisting of navigable objects derived from the conceptual schema, the navigational class schema defines chosen views over the application domain. The navigational class schema is like a redefined conceptual schema for a particular view. Based on the navigational class schema, the navigational context schema defines the navigation space by a set of nodes, links, and indexes that are derived from the navigational class schema.

Abstract Interface Design

The abstract interface design defines how the navigational structure is perceived by users through the application interface. This is done by an abstract interface model. The abstract interface model defines what interface objects a user may perceive, how an interface object may appear, which interface objects will activate navigation, how multimedia interface objects are synchronized and so on.

4.1.3 RMM

RMM, a methodology for designing structured hypermedia, is similar to OOHDM. There are seven steps in the RMM cycle, E-R (Entity-Relationship) design, slice design, navigational design, conversion protocol design, user-interface design, run time behavior design, and construction and testing (Isakowitz, Stohr, & Balasubramanian, 1995). The first six steps are briefly discussed below.

E-R Design

Instead of using an object-oriented model, RMM uses an E-R model to capture the entities and relationships of the entities. The model is presented by an E-R diagram.

Slice Design

One of the differences between OOHDM and RMM is the slice design. Slices define how the information of entities is presented to users and how the users may access the information. The concept of slice provides a way to subdivide attributes of an entity into some meaningful groups. For example, a construction document, as an entity, may contain different types of attributes, such as general information and contents. Slices represent different types of attributes. Thus a "general information" slice may have information about the sender and the receiver of a document.

Navigational Design

RMM does not hard code any links between instances of entities, therefore the navigational paths are specified in generic terms and links are generated at runtime. In RMM, navigational design starts at the entity level. The relationship between two entities is defined by associative relationships. The structural relationships in an entity define relationships among slices of the entities.

RMM uses three types of navigational approaches, conditional indexes, conditional guided tours and conditional indexed guided tours.

Conversion Protocol Design

This step uses a set of rules to transform each element of the E-R diagram into the target platform.

User Interface Design

This step is similar to the user interface design in the OOHDM. It involves the design of layout of information elements and other interface elements such as buttons.

Run Time Behavior Design

This step decides whether the contents of nodes and links are built during application development or dynamically computed on demand at runtime.

4.1.4 Summary of Design Methodologies

All three methodologies adopt a three-schema strategy. One schema defines the hyperbase of applications no matter what terms are used. HDM uses "primitives", OOHDM uses object-oriented models and RMM uses E-R models. A second schema deals with the navigation of the hyperbase defined by the first schema such as the browsing semantics of HDM and the navigational design of OOHDM and RMM. A third schema focuses on how information is perceived by users.

This research will also adopt the three-schema strategy including a conceptual schema, a navigational schema and a presentation schema.

4.2 Malleability Considerations for the System Design

As mentioned in Chapter 2, a "malleable frame" system will support two types of malleability, namely vertical malleability and horizontal malleability. The vertical malleability deals with the process of document processing and the horizontal malleability deals with processing a document for a particular step such as from a Request for Change Order Proposal to a Change Order Proposal. This research will focus mainly on horizontal malleability.

The major issues that need to be considered while designing a "malleable frame" system are document preparation and interpretation, information binding, user interactions, and document workflow process.

4.2.1 Document Preparation and Interpretation

Malleability reflects in document preparation and interpretation in such a way that a document is prepared and interpreted by a standard or shared document schema. Chapter 3 shows the methodology of developing such a document schema with an example of a Request for Change Order Proposal. Different systems share the semantic information of documents so that they can interpret documents exactly the same way.

4.2.2 User Interactions

Human-machine interaction is a two-direction interaction. It is widely agreed that when people use a device or think about a system they do so with the aid of a mental model that characterizes the system. The degree to which the user's mental model matches the conceptual model will determine the user's ability to successfully operate the device. Several researchers have found that providing learners with a clear conceptual model along with operating instructions enhanced learning relative to conditions in which only procedural instructions were provided (Mark, Warm, & Huston 1987). This research tries to provide users with information indexes to help them establish a mental model of a document and related local information although there may be other ways.

Furthermore, capturing user interactions effectively is a way to allow a user to take advantage of malleability. Since the focus of this research is to allow a user to manipulate document elements and related local information simultaneously, research interests will be on providing the user with tools, indexes in this case, to manipulate these

two types of information. The most important one is the index showing both document elements and related local information so that a user can interacted with the two information sources simultaneously and tailor the display of information according to his/her needs.

4.2.3 Information Binding

One of the key issues to achieve malleability is that document elements, especially those about a building component or a construction activity, are properly indexed so that when a system receives a document about "slab on grade" the system will be able to retrieve local information about "slab on grade" exactly. Information binding is different from the document interpretation discussed above, since it deals mainly with how to bind one object with other related objects in another system. Therefore, binding the two types of information, document information and related local information, is the key issue.

As discussed previously, an information index is what makes the binding possible. Such an information index has to either be standardized or shared by collaborating systems. Fortunately, there are many research studies on classifying construction information and the standardization of classifications. One of the standards is the CSI Masterformat. Many applications have already used Masterformat to index construction information. So finding a proper index system should not be a problem. This chapter will review some major construction information classification systems and discuss how to use them for this research.

4.2.4 Document Workflow

Since this topic is related to the vertical malleability, it is not a major focus of this research. This research will only discuss some basic ideas on how to incorporate process information into the "malleable frame" system.

4.3 A "Malleable Frame" System

This section will discuss the integration of malleability considerations with the system architecture of a "malleable frame" system. The system architecture will be discussed first. Then each of schemas will be studied in detail.

4.3.1 System Architecture

Figure 4.1 shows the system architecture of a "malleable frame" system, which is used by the implementation of a prototype system, Kaleidoscope (Zhu, 1999).

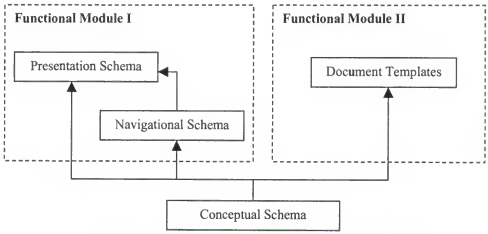


Figure 4.1 The system architecture of Kaleidoscope

Taking advantage of XML technology, the conceptual schema is responsible for the entire hyperbase of applications. Such responsibilities include generating and maintaining an internal generic representation of construction documents, tagging each

document information elements and local information elements, and binding document information elements and related local information elements.

Two functional modules are built on the top of the conceptual schema. The functional module I, which includes the navigational schema and the presentation schema, is for reviewing and processing a document. The functional module II is for preparing construction documents.

Based on the information provided by the conceptual schema, the navigational schema is used for dynamically generating information indexes for users.

The presentational schema deals with presentation issues.

The functional module II has a series of construction document templates and the conceptual supplies standard tags for particular elements of a document. This is how to make a document understandable by another machine that shares the same tags.

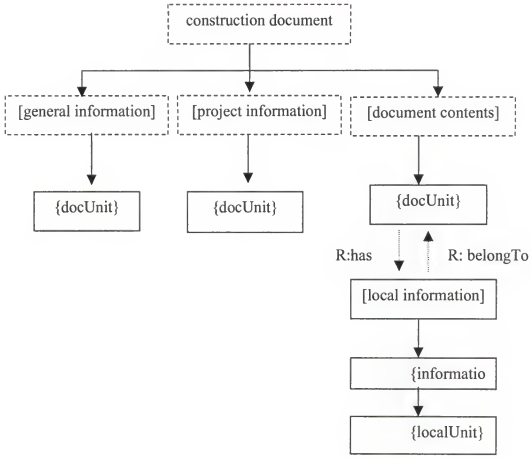
This research will implement the conceptual schema and the functional module one, however, theoretical discussions on the functional module two will be given as well.

4.3.2 The Conceptual Schema

The conceptual schema defines types of information and relationships between the types. To be completely consistent with the document design in chapter three, the conceptual schema also consists of three general types of information, the document information, the project information and the document content. Figure 4.2 shows the structure of the conceptual schema.

For details of the conceptual schema, please refer to "Implementation of Dynamic Hypermedia Generation for Construction Document Processing" (Zhu, 1999). "docUnit" refers to the information units from a document such as project number, sender, recipient,

checklist and so on. A "docUnit" is the actual information container. Similarly, information from local system is structured as well. Following the hypermedia design



Source: Zhu, 1999

Figure 4.2 The conceptual schema

methodology discussed previously, local nodes stand for entities, below which local information types such as scheduling and estimating stand for components, and the attributes of the components are the "localUnits".

4.3.3 The Navigational Schema

Three kinds of index structures will be provided for users to navigate through the hyperbase defined by the conceptual schema, i.e. the document index, the single index and the mixed index. The document index is for manipulating the document only. This index allows a user to tailor the document presentation. The single index lets a user see one piece of information a time. For example, if the user only wants to see the early start time of an activity, this index will allow him to do that. However, the most important index is the mix index that allows a user to tailor both document information and local information simultaneously and present the customized document as one single document. Figure 4.3 shows the generation of the three indexes.

Figures 4.4, 4.5 and 4.6 show examples of the three indexes implemented by Kaleidoscope. Please refer to "Implementation of Dynamic Hypermedia Generation of Construction Document Processing" (Zhu, 1999) for detailed specifications of the index structures.

4.3.4 The Presentation Schema

Each of the above indexes is corresponding to a display template. A display template defines the type and the format of information to be displayed. Please refer to "Implementation of Dynamic Hypermedia Generation of Construction Document Processing" (Zhu, 1999) for detailed specifications of the three corresponding display templates.

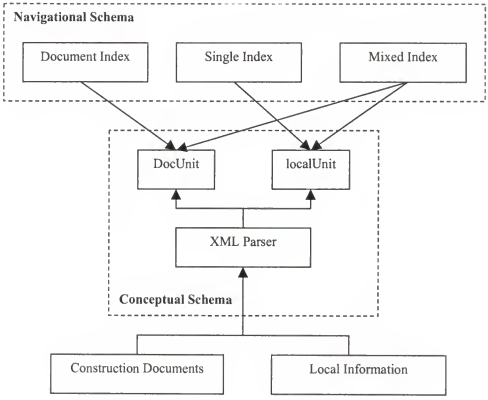


Figure 4.3 The generation of the three indexes

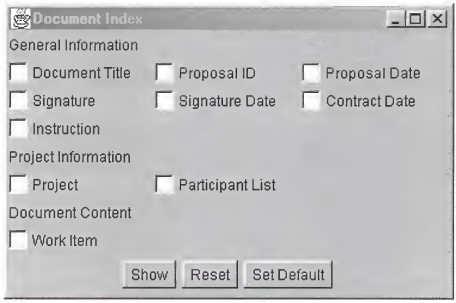


Figure 4.4 A document index

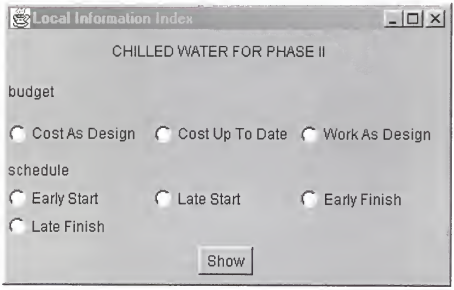


Figure 4.5 A single index

Figure 4.6 A mixed index

Figure 4.7 explains the generation of a presentation. Each entry of an index has a unique tag and two states standing for "checked" and "not checked". The tags used in the navigational schema are also used for the presentation schema. Each tag in the presentation schema is associated with a set of definitions about how information should be displayed, such as font, font size, style and relative positions. Such template is very similar to a style sheet. Therefore, if an entry is checked, the corresponding tag will be sent over to the corresponding template. Based on tag match, the system will be able to understand what information to display and what format will be used for that particular information.

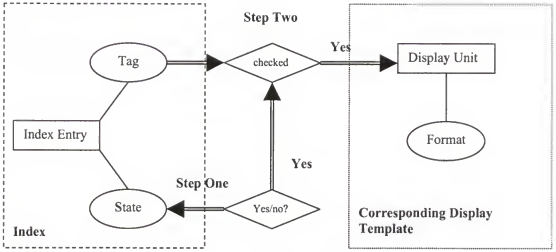


Figure 4.7 A two-step procedure for display

4.4 Construction Information Classification Systems (CICS)

Figure 4.2 illustrates that there is a relationship between a "docUnit" and "localUnit." The relationship is crucial for malleability. To establish and maintain such a relationship an information classification system is needed and shared by different system. Existing classification systems such as the CSI Masterformat can be used to serve this purpose.

4.4.1 A Brief History of Related Research Studies

Although the effort of classifying construction information has been on-going since even before World War II, such work started receiving enough attention only after the war in order to coordinate the reconstruction of so many different countries in Europe. Since then, standardization became a very important issue both in Europe and the United States (Brandon, & Betts, 1995). Table 4.1 below shows some of the major events of this effort.

Table 4.1 Major events of construction information classification

Time	Sponsor	Event
1920	The American Institute of Architecture (AIA)	Publishing the first edition of "Standard Filing System and Alphabetical Index", the first construction material classification
1947	The Joint Working Committee for Building Problems in Sweden	Samarbetskommiten for Byggnadsfragor (SfB) for classifying construction information
1950	The Joint Working Committee for Building Problems in Sweden	Construction Index / Samarbetskommiten for Byggnadsfragor (CI/SfB) for classifying construction information
1963	The Construction Specification Institute (CSI)	CSI format for building construction with 16 divisions
1972	Several organizations including CSI and Construction Specification Canada (CSC)	Publishing the Uniform Construction Index (UCI).
1975	The General Services Administration (GSA)	The "Uniformat" with a 12 major divisions.
1976	The Institution of Civil Engineers	The Civil Engineering Standard Method of Measurement (CESMM) system for quantity survey
1978	CSI and CSC	Publishing the first edition of Masterformat system
1996	The United Classification for the Construction Industry (UUCI)	An updated CI/SfB
Unknown	The International Organization for Standardization (ISO)	A new classification system for the construction industry

At present, the CSI Masterformat, the SfB system, the CI/SfB system, the CESMM system and the ISO system are the most popular classification system (Ioannou, & Liu, 1993, Kang, & Paulson, 1997). Table 4.2 shows a brief comparison those major systems.

Table 4.2 Comparison of existing construction information classification systems

	Masterformat	SfB	CI/SfB	CESMM	ISO
Structure	Hierarchy	Facet	Facet	Hierarchy	Facet
Notation	Decimal system	Mixed system	Mixed system	Mixed system	Under development
Classes	16 Division	Three facets	Five facets	26 Division	Eight facets
Scope of Classification	Operation	Element and operation	Facility, element, and operation	Operation	Facility, space, element, and operation
Application of system	Not applicable to facility and element classifications Need more detailed items for civil works	Not applicable to facility classification Based on the architectural work	Not applicable to element classification for civil works Excellent for architectural works	Not applicable to facility and element classifications Excellent for operation items for civil works	Under development

Source: Kang, & Paulson, 1997

Among those classification systems, the CSI Masterformat is usually the one selected by researchers in the North America because it is developed in the North America and widely accepted by the U.S. and the Canadian construction industry as a standard (Masterformat - manual of practice, 1983, Ioannou, & Liu, 1993, Shrive, 1995, Mincks, & Johnston, 1998, Kang, & Paulson, 1998).

4.4.2 CSI Masterformat

One of the principles of CSI is to establish a standard location for specific information and to state that information only in that location (Masterformat - manual of practice, 1983). The CSI Masterformat is designed to uniquely locate information for a specific building item or activity and only, so there is always a one-to-one relationship between the CSI Master Format classification and building information. Such a classification greatly helps construction professional to locate particular information manually or electronically.

Sixteen Division Specification Format

The sixteen divisions of the CSI Masterformat are fixed in both number and title regardless project types. Under each division, there are different sections covering one portion of the project requirements. A section grouping together related items defines particular materials or products and their installations, or particular administrative or procedural requirements (Masterformat - manual of practice, 1983). An example of the relationship between a division and its sections is shown by Figure 4.3.

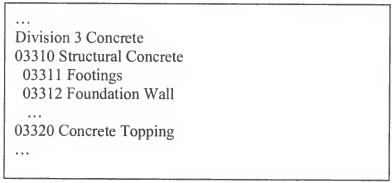


Figure 4.3 An example of the relationship between a division and its sections

Level of Details

The CSI Masterformat identifies three levels of details, namely broadscope, mediumscope and narrowscope. Broadscope titles are for broad categories of work and provide the widest latitude in describing a unit of work. Mediumscope title cover unites of work of more limited scope. Narrowscope titles are used to cover extremely limited and very specific elements of work (Masterformat - manual of practice, 1983).

Standardized Numbers and Titles

The CSI Masterformat suggests a five-digit numbering system for the broadscope and mediumscope titles as shown in Figure 4.1. The first two digits refer to a division and the rest refer to different sections. Therefore, the number "03311" means "Division

3" for "03000", "Cast-in-Place Concrete" for "03300", "Structural Concrete" for "03310" and "Footings" for "03311".

In the above example, "03300" defines a broadscope, "03310" defines a mediumscope and "03311" defines a narrowscope. Normally, Masterformat only defines up to "03310" while more detailed information such as "03311" needs to be added according to a particular project.

4.4.3 Using CSI Masterformat

The CSI Masterformat has been widely used for classifying construction information in different situations. It is used for estimating and accounting purposes (Bertolini, & Syal, 1998), for classifying emerging construction technologies (Ioannou, & Liu, 1993), for integrating safety and health performance into construction CPM (Kartam, 1997), for classifying construction project information (Shahld, & Froese, 1998) and many other applications.

Following are three typical examples that use the CSI Masterformat to classifying construction information.

The Advanced Construction Technology System (ACTS)

The Advanced Construction Technology System (ACTS) is a computer database for classification, documentation, storage and retrieval of information about emerging construction technology (Ioannou, & Liu, 1993). Technologies in the ACTS database are classified according to the CSI Masterformat so that each technology in the ACTS database belongs to exactly one broadscope or mediumscope section.

The documentation of a technology is stored in a file in the ACTS subdirectory whose filename has the form ACTccccc.nnn. The string "ccccc" represents the five-digit

code of the corresponding broadscope or mediumscope section. The extension "nnn" is an indexing number beginning with "001" for the first technology of the corresponding CSI number. Therefore, if a file is named as "ACT03310.001", you know that this file is the first technology in the category of "Structural Concrete".

To search and retrieve a file, the ACTs provides a keyword mode and a CSI mode. For the CSI mode, a user can first access to the Broadscope section and then the mediumscope section. Since each file name is associate with a broadscope or mediumscope title, all technology associated with a broadscope or mediumscope title will then be displayed under the corresponding section.

The IKIS-Safety

The IKIS-Safety, Integrated Knowledge Intensive System for Construction Safety and Health Performance Control, is a proactive safety system that integrates safety and health issues into all phases of a construction project from design, construction to maintenance (Kartam, 1997).

The IKIS-Safety uses CSI Masterformat as a common data set between a safety record database and a construction schedule. The system first classifies safety records by using CSI Masterformat and other mechanism such as keywords and 24 OSHA (Occupational Safety and Health Administration) subparts. Then when checking safety records for a certain activity, a temporary file with an activity ID, a CSI activity code and a comment field is generated. This temporary file is passed to the database management system. Since safety records are stored according to CSI's broad, medium and narrow scope approach, the corresponding safety records can then be matched with the activity.

In this system, there are two important things that need to be noticed. First, information is classified up to the narrowscope level. Second, each activity in scheduling is also assigned a CSI code besides its activity ID.

The Project Management Information Control System (PMICS)

The PMISC is designed for construction professionals to enter information for a wide variety of project events, cross-reference the various bodies of information, and use the information to monitor and control various aspects of a construction project (Shahld, & Froese, 1998). The system incorporates the CSI Masterformat into its conceptual schema in order to classify information. However, it is recognized that the CSI Masterformat is not precise enough to use for differentiating all of the individual items in an estimating. Thus the specification sections are related to a more detailed work breakdown structure (WBS) classification scheme adopted from the American Society of Professional Estimators (ASPE) (Shahld, & Froese, 1998).

The system is implemented by relational database technology. In total 25 tables are used. Among them a table called WBS Item lists all project activities is keyed by using WBS ID and Specification ID (Shahld, & Froese, 1998). Thus each activity of a project has a one-to-one relationship with the combination of WBS ID and Specification ID. This is how an individual activity is managed by PMICS.

4.4.4 The Use of the CSI Masterformat for Malleability

The previous discussion shows that either the CSI Masterformat alone, i.e. ACTS and IKIS-Safety or the CSI Masterfomat with some extension i.e. PMICS can very well classify construction information at a detailed level. For the purpose of this research if such a classification system can be shared by all project participants, a building item or a

construction activity described by one system can be interpreted correctly by another system. Since it is not the focus of this research to further investigate this issue, it is assumed that the existing classification systems such as the CSI Masterformat can be used for the purpose of this research.

4.5 Summary

A "malleable frame" system is a hypermedia system. Major hypermedia design methodologies such as HDM, OOHDM and RMM have been widely used. Based on these methodologies, this research adopts a three-schema strategy, i.e. a conceptual schema, a navigational schema and a presentation schema. The conceptual schema is for maintaining a hyperbase that consists of document information elements and local information elements. The navigational schema defines ways that users can access to the hyperbase. The presentation schema is for presentations of documents and customized information.

Malleability is basically reflected in the conceptual schema and the navigational schema. The conceptual schema is defined according to design of the "malleable frame" and each "docUnit" is associated with a unique tag. In this way, if such tags are shared by different system, those systems will be able to interpret a document in the same way. Another reflection of malleability in the conceptual schema is that document information elements and related local information are bonded via a shared or standardized information index system. Therefore information from two different sources forms one logical hyperbase that is represented as the conceptual schema. Once a hyperbase is formed, tools are provided for users to manipulate the hyperbase and tailor information presentations in terms of content and format according to their needs. Such capabilities

are the most direct reflection of malleability. The navigational schema, providing three types of indexes, furnishes users with such capabilities.

In order to bind document information elements with related local information, a shared or standardized information index system must be available. Many research studies (Ioannou, & Liu, 1993, Kartam, 1997, Bertolini, & Syal, 1998, Shahld, & Froese, 1998) have shown that the CSI Masterformat is an ideal tool, therefore this research assumes that the CSI Masterformat can be used as the information index system.

CHAPTER 5
SYSTEM IMPLEMENTATION

The implementation of a prototype "malleable frame" system, called Kaleidoscope, is accomplished by using XML technology and Java programming language.

5.1 Overview of Implementation Technology

5.1.1 Document Representation and the Document Object Model (DOM)

No matter what it is, a "valid" document or a well-formed document, an XML document is represented by a tree structure. The tree structure is used as a logical structure of XML documents. A sample document segment is shown in Figure 5.1, and the corresponding tree structure is shown in Figure 5.2.

Based on such a tree structure, the Document Object Model (DOM) Application Programming Interface (API) provides tools to build documents, navigate their structure, and manipulate their elements and content. The DOM has a DOM (Core) level 1 for dealing with XML documents and a DOM (HTML) level 1 for handling HTML documents. Here we only use the DOM (Core) level 1 API.

According to the DOM (Core) level 1 API, there are 13 node types in total (Document Object Model Specification, 1999, Walsh, 1997). They are *Document*, *DocumentFragment*, *DocumentType*, *EntityReference*, *Element*, *Attr*, *ProcessingInstruction*, *Comment*, *Text*, *CDATASection*, *Entity*, *and Notation.* The COM

core API provides various kinds of classes and methods for manipulating each type of nodes. Please refer to http://www.w3c.org/ for a list of COM (Core) Level 1 API and details about DOM.

5.1.2 XML Parsers

There are several parsers available for developers. Some parsers, such as the IBM parser (XML for Java, 1997) and the Microsoft parser (Paoli, Schach, Lovett, Layman, & Cseri, 1997) not only do document validation but also generate the parse tree to allow DOM API to manipulate the document. Some other parsers do document validation only. In this project, the IBM parser is used.

```
<change_order>
    <sender_info>
        <name>CISE</name>
        <address>University of Florida</address>
    </sender_info>
    <receiver_info>
        <name>Clark Construction</name>
        <address>3476 NW, Gainesville</address>
    </receiver_info>
```

Figure 5.1 A sample of document segment

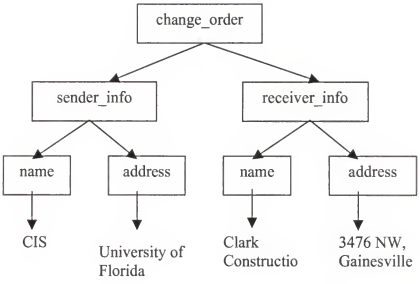


Figure 5.2 the tree structure of the document segment

5.1.3 XML and Web Database Integration

Since XML is merely a meta-language for defining open data format, it can be used to define other languages and applications. One of such applications is the Web distributed data exchange (WDDX) technology (ColdFusion White Paper, 1997, Forta, 1998, Allaire, 1998). Created by Allaire, WDDX tries to solve key problems in exchanging data between Web applications by using some standard data format. As of this writing, WDDX is not a formal standard yet and it has not been submitted to the W3C or any other standards body. However, WDDX is freely available for use and redistribution, and is based on open, standards-based technologies such as XML 1.0.

The WDDX has three basic terms, *Packet*, *Serializing* and *Deserializing* (Forta, 1998, Allaire, 1998). A WDDX *Packet* is any chunk of data that has been stored in the WDDX format. *Serializing* is the process of taking some pieces of data and converting it

into a WDDX *Packet*. *Deserializing* is the opposite process of *Serializing*, which takes the data out of an existing WDDX *Packet*.

The idea of this technology is to turn any kind of data, a simple integer or a complex structure, into a chunk of ASCII text. That chunk of text is stored in the WDDX format. When the data is needed again, it is then translated back into the format as it was. Since the WDDX data format uses XML, the chunk of data is thus portable. For example, an application uses WDDX to take a complex array in ColdFusion, serialize it into XML, send it to other requesting applications, and then deserialize from XML into an object that is native to the applications.

As a XML application, WDDX provides a new way to allow different programming environments to share data. That is one of the major features that promise WDDX a good future.

Besides ColdFusion who initiates the efforts of integrated XML into database systems, other database vendors, such as Oracle, Informix, Object Design and POET, are starting moving towards this direction (Mendel, 1999).

5.1.4 Java Programming Language

Java programming language is designed for internet/Web applications. It provides a rich set of classes dealing with intenet/Web programming, user interface programming, concurrent programming and many other applications. These features make Java programming language an ideal tool for the implementation of Kaleidoscope.

5.2 Implementation Strategies

Following the design details, the implementation of Kaleidoscope is composed of three modules. Module one focuses on generating and maintaining the conceptual schema

by using XML technology and the IBM parser. An API (Application Programming Interfaces), implemented by class "myDocument", is provided for manipulating the conceptual schema. Module two is for implementing the navigational schema based on the services provided by module one. Module three is the implementation of the presentation schema.

Figure 5.3 shows the flow of document information within the system.

The system starts reading in a construction document that is in XML format. A XML parser will parse the document first. After parsing, the system then understands what type of document it is and what building components are mentioned in the document. The system handler will handle tag matching so that tags of a default view will be read in and corresponding document information will be sent to the corresponding template for display. The indexes are generated by the document handler according to different documents. Users may interact with the indexes to change default views to particular documents.

The actual implementation is composed of three modules. The XML parser and the document handler are implemented as module one. Module two includes the indexes and the default view. Module three deals with the templates and presentation.

Appendix B includes some screen shots of Kaleidoscope. For details of the implementation of Kaleidoscope, please refer to “Implementation of Dynamic Hypermedia Generation for Construction Document Processing" (Zhu, 1999).

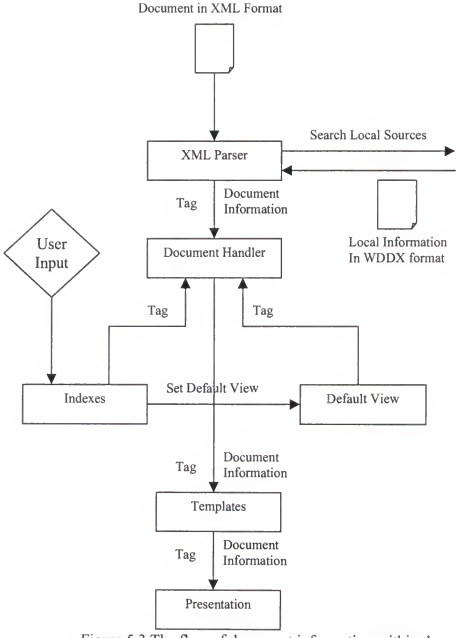


Figure 5.3 The flow of document information within the system

5.3 Assumptions and Limitations

5.3.1 Assumptions

The Kaleidoscope project is based on several assumptions that are related to the two inputs, namely the construction documents and the associated local information.

- The project uses XML to represent structured construction documents. Since such practice has not been a standard approach yet, assumptions about XML tags and document structures are needed. For instance, as shown in Figure 5.4, the project may use following XML tags denoting some nodes in a construction document.

```
<documentType docName="changeRequest" id="CH-123">
Request for Change Order Proposal
</documentType>
<project projectNumber="1">
    <name>Gator Hospital</name>
</project>
```

Figure 5.4 An example of a construction document in XML format

In the above example, the node names, such as "documentType", "project" and "name", and attribute names, such as "docName" and "projectNumber", should be part of construction document vocabulary. This vocabulary has to be an industrial standard or at least shared by systems. Currently, such vocabulary does not exist. And there is no industrial standard. Therefore in the project we need to assume our own vocabulary.

- One of the major features of Kaleidoscope is its ability to combine a document information element with related local information. As discussed, such capability relies on a information index system that is shared by different systems. Without

giving details, this research assumes that the CSI Masterformat can be used for this purpose.

- Another input of the system is information from the local system. Normally, the information is stored in various kinds of databases. In order to make Kaleidoscope portable, this research assumes to use a new technology called WDDX (Web Distributed Data eXchange). The records retrieved from local database are assumed in WDDX format.

5.3.2 System Limitations

Major limitations of Kaleidoscope are listed as following.

- Kaleidoscope can only deal with a small hyperbase and does not allow users to go beyond that small byperbase composed of a document and related local information. In real applications, a user may need more local information than what is currently provided by the Kaleidoscope. That is to say Kaleidoscope needs to provide gateways to other systems, scheduling systems, estimating systems and so on. Otherwise, Kaleidoscope may eventually confine a user's capability instead of improving it.
- Kaleidoscope currently only deals with one document at a time. There are cases that a user may need to open two or more documents simultaneously. Such situation has not been studied carefully yet.
- Currently, Kaleidoscope only allows one type of document unit to be active and searchable for related local information at one time. An extreme case will be that all units are active. Further studies are needed to optimize such situation.

- Kaleidoscope currently can only deal with simple data structures, such as strings. More complex data structures, such as data structures for video, audio, CAD, 3D and so on, cannot be handled by the system at present.
- Vertical malleability is an important part of malleability. This research only focuses on horizontal malleability, leaving vertical malleability only to a little theoretical analysis. Further studies are needed on this topic.

5.4 Summary

This chapter summarizes the implementation of Kaleidoscope, a prototype "malleable frame" System. Details of the implementation and assumptions and limitations of Kaleidoscope are discussed in "Implementation of Dynamic Hypermedia Generation for Construction Document Processing" (Zhu, 1999).

CHAPTER 6
HYPOTHESIS TESTING

6.1 Introduction

Previous discussions show that it is technically feasible to build a "malleable frame" system. This chapter will answer a basic question, which is "Is the 'malleable frame' system a better system? "

To answer the question, two types of test systems are set up. One is called a standard system and simulates a system that cannot automatically place a received document and related local information into one screen. The other, called a "malleable frame" system, simulates a system that can automatically put a construction document and related local information into one screen, which implies that the local information system understands what the received document is and what to do with it. Such capabilities are basic features of a "malleable frame" system. Four test cases, which are documents of Request for Change Order Proposals, will be applied. Users will be required to make a decision on whether a certain change will incur extra cost. The objective is to find out if there is a significant difference in terms of time between the two systems for users to make a decision.

In the following sections, details on test plans, test system set-up, test cases, data collection and data analysis will be discussed.

6.2 Pilot Study

A pilot study was conducted to gain knowledge and experience regarding the design of the test system. The test system of the pilot study used three test cases that were shared by the standard system and the "malleable frame" system. The three test cases were designed to represent the three possible cases shown in Table 6.1. The pilot study used graduate students of M.E. Rinker Sr., School of Building Construction (BCN). Forty students were participated in the test. Twenty students used the standard system and each of them needed to test all three cases. The other twenty students used the "malleable frame" system and each of them tested the same three cases. The experience gaining from the pilot study suggested,

- A larger sample size,
- Being more specific about asking participants' experience, i.e. using "1-5 years of experience" rather than "very familiar,"
- Using pair-wise comparison,
- Controlling test steps,
- Controlling timing,
- Re-designing test cases for pair-wise comparison.

Based on the pilot study, improvements were made to the final test system.

6.3 Test Plans

Change orders are typical to almost all kinds of construction projects. Figure 6.1, which include many types of documents such as a Request for Information, a Request for Change Order Proposal and a Change Order Proposal, shows a typical document flow of

a change order process. In this research, we will focus on one step in a contractor's perspective. That step is that after receiving a Request for Change Order Proposal a contractor needs to prepare a return document, a Change Order Proposal.

The consequence of a change may be either changes in cost or no change in cost. Putting it into the context of this research adds another dimension, which is whether the document is about defined items or undefined items. If the change order is about some items that have already existed in the user's local systems, the items are defined. Otherwise, they are undefined. Table 6.1 shows possible combinations of these two dimensions.

Table 6.1 Possible combinations of the two dimensions regarding a change

	No change	**Change**
Defined	Possible	Possible
Un-defined	Not Possible	Possible

Among all combinations, three of them are possible. These three cases, denoted as "d/c", "d/nc" and "ud/c", are "defined with change", "defined without change" and "un-defined with change" respectively. Figure 6.2 shows a typical process of this step.

Since a "malleable frame" system is supposed to be able to put a received document and related local information in the same window for users, it is more valuable to identify whether the received document is about some items that have been defined by the user's local system or not. This idea will be reflected in the test cases.

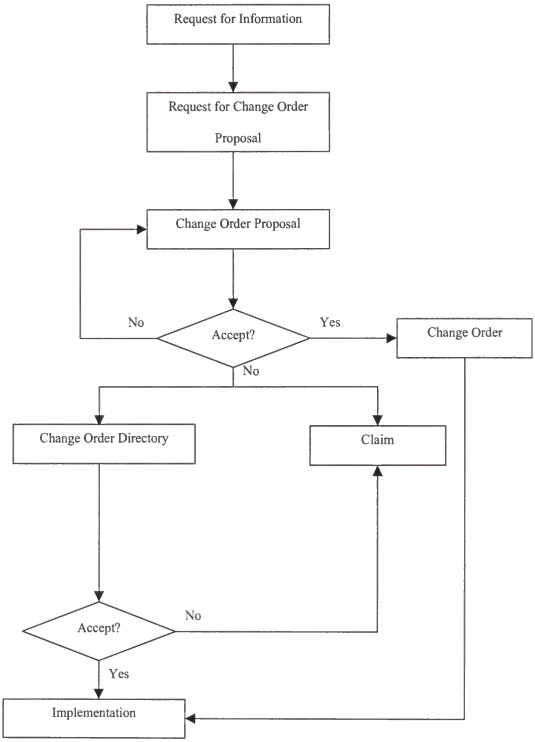


Figure 6.1 Document flow of the change order process

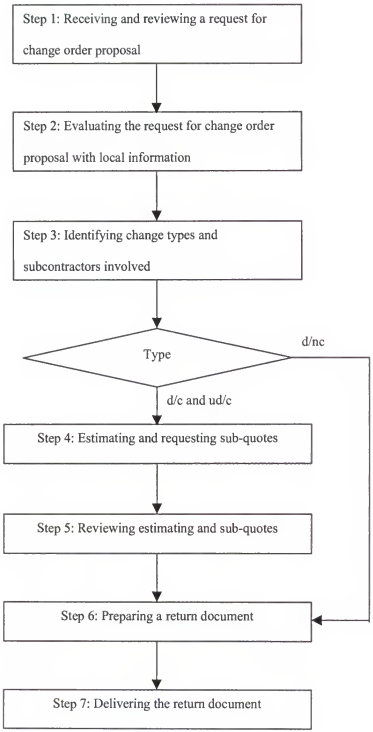


Figure 6.2 A typical step for preparing a change order proposal

Figure 6.2 shows a 7-step process for preparing a change order proposal. Among the seven steps, this research is only interested in the first three steps while only step 2 and step 3 should be different between the standard system and the "malleable frame" system. Thus the test variable is designed to measure the time for completing up to step 3. Figure 6.3 shows the differences between the systems and the setup of the test variable.

In other words, the test will determine if there is a statistically significant difference in time that it takes to decide whether the change order request is a "cost" or "no cost" change.

	Standard System	Malleable Frame System	Test Variable
Step One	Same	Same	
Step Two	Different	Different	T
Step Three	Different	Different	
Step Four	Same	Same	
Step Five	Same	Same	
Step Six	Same	Same	
Step Seven	Same	Same	

Figure 6.3 Difference between the two test systems and the test variable

For the sake of simplicity, the tests will only use one type of local information, schedule information, because it does not matter how many types of local information are included in the tests.

6.4 Test Cases

Several principles are followed in designing test cases:

1. The cases are simple enough so that people with minimum practical experience in dealing with change order cases can handle the tests. The purpose of doing this is to reduce any time differences caused by different level of construction experience and knowledge.
2. The cases should be different enough to reduce bias. This is saying that one case should not be related to another in any way. The differences are reflected in the documents such that they refer to different building items in different cases. Also the differences are reflected in scheduling such that the items belong to different categories.
3. Although there might be some bias in term of the testing process, i.e. the user gets more familiar with the system when doing the fourth test case than when doing the first, sample tests offer an effective way to reduce such bias to a minimum level.
4. In order to obtain a pair-wise comparison, two pairs of cases are designed. One pair includes Case 1 and Case 3. The other includes Case 2 and Case 4. Besides, the average time of the standard system and that of the "malleable frame" system consists of another derived pair. Therefore the tests will have three pairs shown in Table 6.2. Although cases in each pair are different cases to avoid bias, they are designed with comparable features such as the size of documents, the size of images, lines of text, the size of related schedule information so that it is reasonable to assume that they are comparable.

Pair 1, Case 1 and Case 3, represents a situation that items or activities that a Request for Change Order Proposal discusses have been defined in the document viewer's local system. Pair 2, Case 2 and Case 4, represents a situation that items or activities that a Request for Change Order Proposal discusses have not been defined in the document viewer's local system. Pair 3, average cases of the standard system and the "malleable frame" system, represents a cross media and general condition. Since these pairs represent different situations, the hypothesis test will be repeated for each of the situations.

Table 6.2 Pair-wise Cases

		Malleable Frame System		
		Case 3	Case 4	Average
Standard System	Case 1	Pair 1	-	-
	Case 2	-	Pair 2	-
	Average	-	-	Pair 3

6.5 Test System Design

In addition to test case design, major considerations regarding the test system design include sample testing, flow control, timing and survey. Details of the test system are discussed in Appendix C.

6.5.1 Sample Testing

One of the important steps to reduce bias introduced by learning curve is conducting sample testing before taking actual tests. Two sample tests are used by the test systems, one for the standard system and the other for the "malleable frame" system.

Sample tests are designed in such a way that the process for conducting sample testing is exactly the same as taking normal tests. In this way, after a couple of times of practice, even just once, a user can be reasonably confident to take normal tests.

6.5.2 Flow Control

Since the test system is on-line, it is designed for self-help tests, which means there will not be anybody out there helping users to complete tests. Thus assuring that all users follow the same process is extremely important. So the test system uses a lot of user interface features to control the flow of testing to make sure that every user follows the same process. Appendix C has detailed explanations on this topic.

6.5.3 Timing

Time is crucial for this research. What is important to this research is the period of time from the point that all relevant information is loaded to the point that a user's decision is made. This time period is controlled by user interactions so that unrelated time will not be included. Please refer to Appendix C for details

6.5.4 Survey

Besides time, other information such as the user's knowledge about change orders and the user's satisfaction with using the "malleable frame" system is collected. Survey questions were asked after each "malleable frame" test was completed. Appendix C has a sample of the survey.

6.6 Data Collection

6.6.1 Sampling

This research used samples of students of M.E. Rinker, Sr., School of Building Construction (BCN). Reasons for such a substitution are that firstly most of BCN students, especially seniors and graduate students, have relevant construction education and some even already have relevant construction experience. Therefore they understand how to deal with a Request for Change Order Proposal very well. Secondly, the objective of the test is not to test how the systems can handle complicated information of a real construction project by professionals. Rather it is to compare a simple feature between two kinds of systems since malleability is reflected as simply interface features in the test systems. Thirdly, the test cases are deliberately designed to be simple enough so that more work experience and extra knowledge will not become an advantage and will certainly not affect the time needed for making a simple decision. Based on these assumptions, BCN graduating seniors and graduate students will be used as samples for this test.

6.6.2 Sample Size

Ideally a sample size should be decided by the following formula (Byrkit, 1987)

$$n = (Z_{\alpha/2} * \sigma / E)^2$$

Where, α is the level of significance ($1-\alpha$ is called confidence level); σ is the standard deviation and E is called "maximum error". In this research σ and E are unknown, so other approaches are required. Some research suggests that a sample size of 30 or over is good enough and acceptable (Marks, 1997). Because if a sample size is larger than 30, the Central Limit Theory can be invoked and the distribution of the

sample average can be regarded as normal. In this research, a sample size of 46 is applied.

6.6.3 Collected Data

Several types of data, shown in Table 6.3, are collected via the "Survey Answer Sheet" (see Appendix C).

In total, there are 49 samples collected. However, three of them are incomplete (They only have data for sample tests). Among the rest 46 samples, one does not indicate years the level of experience, so there are 45 samples used for user satisfaction analysis. Overall, 46 samples are used for hypothesis testing (See Table 6.4).

Table 6.3 Data Collected

Data and information	Reasons to collect
Knowledge of Change Orders	To collect background information
Time	To compare the two systems
User satisfaction	To check user satisfaction to the "malleable frame" system
Further control over display	To understand user's needs for malleability

Following are the data compiled according to each of the types. Analysis will be given later in this chapter.

Knowledge of Change Orders

The survey asked respondents about their knowledge of construction change orders on a scale of "Excellent (more than 10 years of working knowledge of change orders) ", "Very familiar (5-10 years of working knowledge of change orders) ", "Familiar (0-5 years of working knowledge of change orders) ", "Not Familiar (school experience)" and "Don't know at all".

This information is used as background information only and nothing more since this research is not focused on comparing time between different knowledge groups.

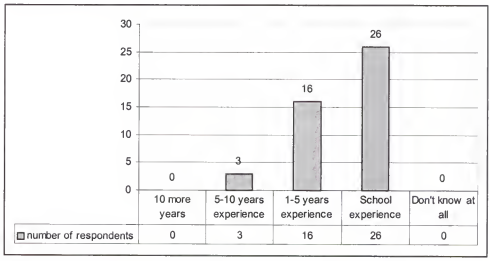


Figure 6.4 Respondents by knowledge of change orders

Figure 6.4 shows the number of respondents by the knowledge of change orders. It shows that all of the respondents have at least school knowledge of change orders.

Time for Completing Tests

Time for completing test cases is collected and compiled in pair-wise format, shown in Table 6.4. These data are used for computing sample statistics. In the table, "SS" stands for "Standard System" and "MFS" stands for "Malleable Frame System."

User Satisfaction

Beside quantitative analysis based on time, two questions are asked to find out user's satisfaction towards the "malleable frame" system in order to have a qualitative understanding as well. The first question is "Do you find it helpful by putting the request for change order proposal and related project information on the same page when dealing with change orders?" Answers were collected on a scale of "Extremely helpful", "Very helpful", "Helpful", "Not very helpful" and "Not helpful at all".

Table 6.4 Time for Completing Tests (Unit: second)

	Pair One		Pair Two		Pair Three	
	Case 1 (SS)	Case 3 (MFS)	Case 2 (SS)	Case 4 (MFS)	Average (SS)	Average (MFS)
1	23	52	39	31	31	42
2	17	47	24	20	21	34
3	84	66	58	77	71	72
4	36	37	30	42	33	40
5	27	37	14	41	21	39
6	25	51	46	54	53	36
7	33	25	66	28	50	27
8	55	26	57	56	56	41
9	41	25	68	34	55	30
10	52	36	26	45	39	41
11	22	38	31	21	27	30
12	55	34	36	49	46	42
13	28	51	20	32	24	42
14	32	15	51	27	42	21
15	76	32	75	49	76	41
16	53	41	48	57	51	49
17	66	34	70	21	68	28
18	32	15	51	27	42	21
19	42	32	33	14	38	23
20	37	17	36	21	37	19
21	12	33	13	28	13	31
22	66	34	70	21	68	28
23	40	36	32	26	36	31
24	62	25	38	27	50	26
25	70	33	17	27	44	30
26	63	29	47	44	55	37
27	77	82	77	74	77	78
28	45	38	24	33	35	36
29	70	24	60	25	65	25
30	23	26	10	8	17	17
31	42	38	17	8	30	23
32	44	47	40	21	42	34
33	36	40	80	32	58	36
34	60	27	21	39	41	33
35	55	34	36	49	46	42
36	38	80	26	37	32	59
37	60	27	21	39	41	33
38	89	38	62	36	76	37
39	142	26	39	80	91	53
40	137	37	17	14	77	26
41	67	57	22	111	45	84
42	86	22	102	39	95	31
43	138	41	39	59	84	50
44	138	22	42	54	90	38
45	86	39	33	30	60	35
46	111	37	92	39	102	38

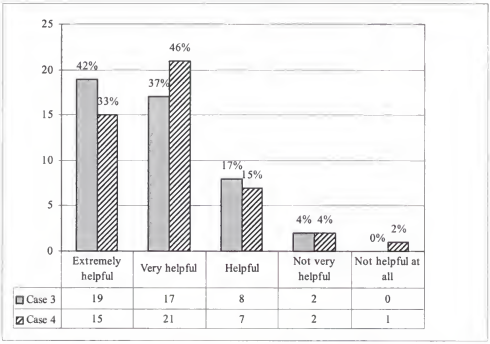


Figure 6.5 Answers to questions about user satisfaction

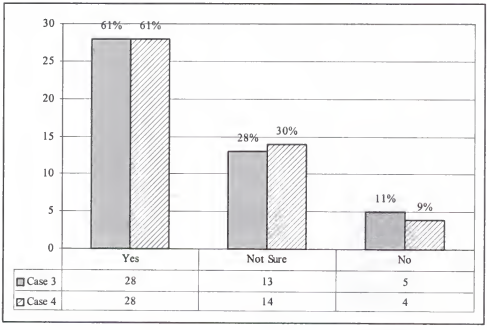


Figure 6.6 Answers to the questions regarding controls over display

The second question is "As an end user, do you wish to have control over how the request for change order proposal and the related project information are presented to you if they are on the same page?" Answers were collected on a scale of "Yes", "Not sure" and "Not."

The results for these two questions are shown in Figures 6.5 and 6.6 respectively.

6.6.4 User Satisfaction within the Same Experience Level

This section discusses some observations about user satisfaction within the same experience level.

With five or more years of experience

Table 6.5 shows the results collected from people with five or more years of experience.

Table 6.5 Data for the Group with Five or More Years of Experience

No.	Case 1 (Second)	Case 3 (Second)	Case 2 (Second)	Case 4 (Second)	Case 3 Q1	Case 4 Q1	Case 3 Q2	Case 4 Q2
1	27	37	14	41	EH	EH	Yes	Yes
2	60	27	21	39	EH	EH	Yes	Yes
3	52	36	26	45	EH	EH	Yes	Yes
Average	**50**	**33**	**20**	**42**				

Note: "EH" stands for "Extremely Helpful"; "Q1" stands for the first question of the survey; "Q1" stands for the second question of the survey.

According to Table 6.5, all of the respondents in this group (with five to ten years of experience) indicate that the "malleable frame" system is "Extremely helpful" and users would like to have more controls over display. However, since there are only three samples in this group, it is impossible to make any statistical decision.

With One to Five Years of Experience

Table 6.6 shows the results collected from people with one to five years of experience.

Table 6.6 Data for the Group with One to Five Years of Experience

No.	Case 1 (Second)	Case 3 (Second)	Case 2 (Second)	Case 4 (Second)	Case 3 Q1	Case 4 Q1	Case 3 Q2	Case 4 Q2
1	84	66	58	77	EH	EH	Yes	Yes
2	55	26	57	56	VH	EH	Yes	Yes
3	22	38	31	21	VH	VH	NS	NS
4	55	34	36	49	EH	EH	NS	NS
5	32	15	51	27	VH	VH	Yes	Yes
6	32	15	51	27	VH	VH	Yes	Yes
7	12	33	13	28	H	H	No	No
8	40	36	32	26	NVH	NVH	Yes	Yes
9	62	25	38	27	H	H	Yes	Yes
10	70	33	17	27	VH	VH	Yes	Yes
11	77	82	77	74	EH	EH	Yes	Yes
12	70	24	60	25	EH	EH	NS	NS
13	55	34	36	49	EH	EH	NS	NS
14	38	80	26	37	EH	EH	Yes	Yes
15	138	41	39	59	VH	VH	No	Yes
16	138	22	42	54	VH	VH	Yes	Yes
Average	**61**	**38**	**41**	**41**				

Note: "EH" stands for "Extremely Helpful"; "VH" stands for "Very Helpful"; "H" stands for "Helpful"; "NVH" stands for "Not Very Helpful"; "Q1" stands for the first question of the survey; "NS" stands for "Not Sure"; Q1 stands for the second question of the survey.

Figure 6.7 shows the number and the percentage of responses relating to user satisfaction at different levels, which are "Extremely helpful", "Very helpful", "Helpful", "Not very helpful", and " Not helpful at all."

Figure 6.8 shows the number and the percentage of responses regarding user control over the document display format.

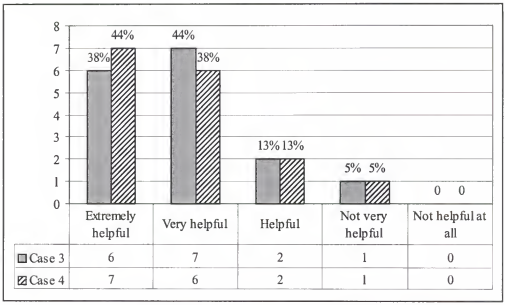


Figure 6.7 Answers to the question about user satisfaction by people with one to five years of experience

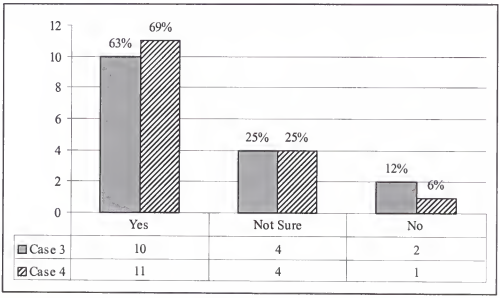


Figure 6.8 Answers to the question regarding user control over the document display format by people with one to five years of experience

With School Experience

Table 6.7 shows samples collected from people with school experience.

Table 6.7 Data for the Group with School Experience

No.	Case 1 (Second)	Case 3 (Second)	Case 2 (Second)	Case 4 (Second)	Case 3 Q1	Case 4 Q1	Case 3 Q2	Case 4 Q2
1	23	52	39	31	VH	VH	Yes	Yes
2	17	47	24	20	EH	NHAL	No	No
3	36	37	30	42	EH	VH	Yes	Yes
4	25	51	46	54	VH	VH	Yes	Yes
5	33	25	66	28	EH	VH	Yes	Yes
6	41	25	68	34	EH	EH	Yes	Yes
7	60	27	21	39	EH	EH	Yes	Yes
8	28	51	20	32	H	VH	Yes	Yes
9	76	32	75	49	VH	H	Yes	Yes
10	53	41	48	57	EH	VH	No	No
11	66	34	70	21	VH	VH	Yes	Yes
12	42	32	33	14	H	VH	NS	NS
13	37	17	36	21	EH	EH	Yes	Yes
14	66	34	70	21	VH	VH	Yes	Yes
15	63	29	47	44	EH	VH	Yes	Yes
16	45	38	24	33	VH	VH	No	No
17	23	26	10	8	H	H	NS	NS
18	42	38	17	8	NVH	NVH	No	No
19	44	47	40	21	H	H	NS	NS
20	36	40	80	32	EH	EH	Yes	NS
21	89	38	62	36	VH	VH	Yes	Yes
22	137	37	17	14	H	H	NS	NS
23	67	57	22	111	VH	VH	NS	NS
24	86	22	102	39	VH	VH	NS	Yes
25	86	39	33	30	H	H	NS	NS
26	111	37	92	39	EH	EH	NS	NS
Average	55	37	46	34				

Note: "EH" stands for "Extremely Helpful"; "VH" stands for "Very Helpful"; "H" stands for "Helpful"; "NVH" stands for "Not Very Helpful"; "NHAL" stands for "Not Helpful At All"; "Q1" stands for the first question of the survey; "NS" stands for "Not Sure"; Q1 stands for the second question of the survey.

Figure 6.9 and 6.10 indicate that most of the people with school experience reported that the "malleable frame" system was helpful to both cases and many of them would like to have more user control over the document display format.

The observations obtained from Table 6.5 and Figure 6.7 to 6.10 indicate that all three groups, namely 5 to 10 years of experience, 1 to 5 years of experience and school experience, have similar patterns. All three groups appear to indicate that the majority reported that the "malleable frame" system was "Helpful." (See Table 6.5 and Figure 6.7 and 6.9) Meanwhile, many with less than five years of experience indicated that they were not sure it they needed more control over the document display format (See Figure 6.8 and 6.10).

6.6.5 User Satisfaction Comparison between Different Experience Groups

The previous section discusses observations about user satisfaction within the same experience level. In this section, focus is on the comparison of user satisfaction between groups of different experience levels.

Case 3

Figure 6.11 and 6.12 show the comparison of user satisfaction with using the "malleable frame" system. Figure 6.12 shows accumulative values. Both diagrams indicate that the more experienced users are the more satisfied they are.

Figure 6.13 and 6.14 shows the comparison of the desire for more controls over display. Both diagrams seem to indicate the same results, which there is a larger percentage of experienced users who would like to have user controls over the document display format.

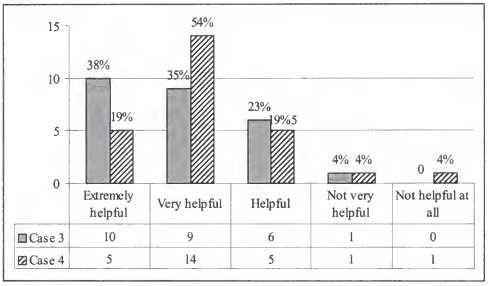


Figure 6.9 Answers to the question about user satisfaction by people with school experience

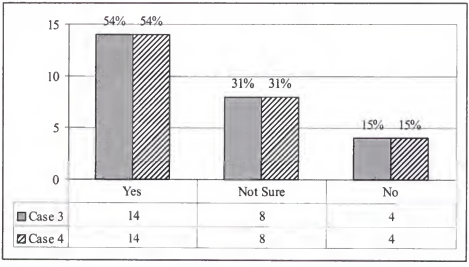
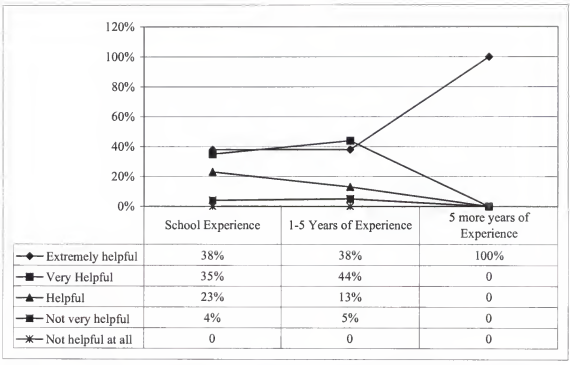
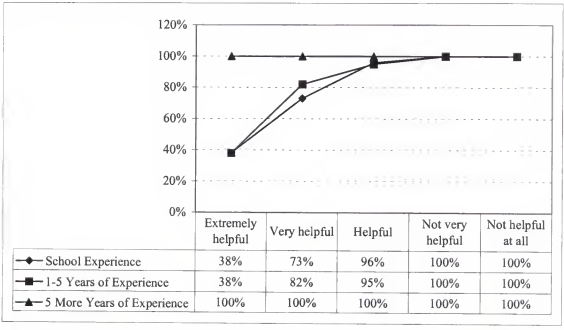


Figure 6.10 Answers to the question regarding controls over display by people with school experience



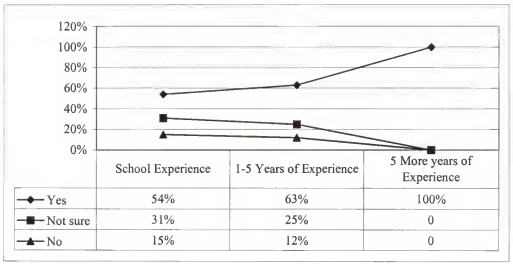
	School Experience	1-5 Years of Experience	5 more years of Experience
Extremely helpful	38%	38%	100%
Very Helpful	35%	44%	0
Helpful	23%	13%	0
Not very helpful	4%	5%	0
Not helpful at all	0	0	0

Figure 6.11 Answers to the question about user satisfaction for Case 3 by experience



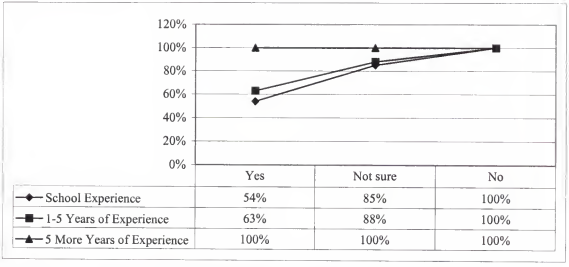
	Extremely helpful	Very helpful	Helpful	Not very helpful	Not helpful at all
School Experience	38%	73%	96%	100%	100%
1-5 Years of Experience	38%	82%	95%	100%	100%
5 More Years of Experience	100%	100%	100%	100%	100%

Figure 6.12 Accumulative percentage of user satisfaction for Case 3 by experience



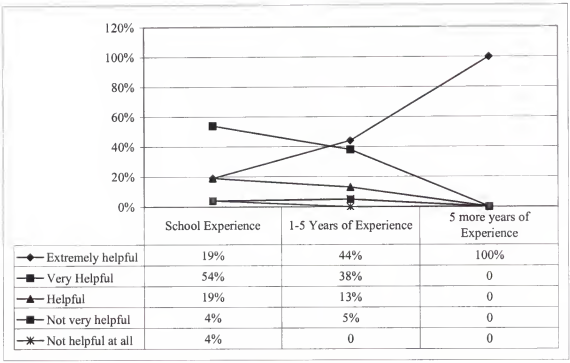
	School Experience	1-5 Years of Experience	5 More years of Experience
Yes	54%	63%	100%
Not sure	31%	25%	0
No	15%	12%	0

Figure 6.13 Answers to the question regarding controls over display for Case 3 by experience



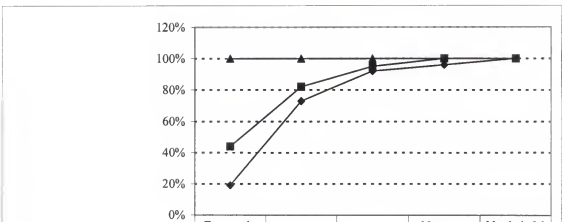
	Yes	Not sure	No
School Experience	54%	85%	100%
1-5 Years of Experience	63%	88%	100%
5 More Years of Experience	100%	100%	100%

Figure 6.14 Accumulative percentage of user's desire for more user control over the document display format for Case 3 by experience



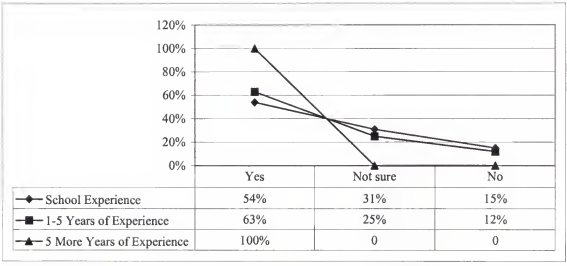
	School Experience	1-5 Years of Experience	5 more years of Experience
Extremely helpful	19%	44%	100%
Very Helpful	54%	38%	0
Helpful	19%	13%	0
Not very helpful	4%	5%	0
Not helpful at all	4%	0	0

Figure 6.15 Answers to the question about user satisfaction for Case 4 by experience



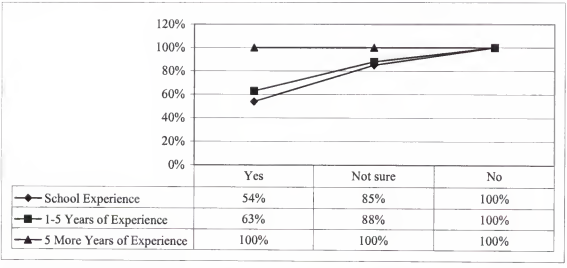
	Extremely helpful	Very helpful	Helpful	Not very helpful	Not helpful at all
School Experience	19%	73%	92%	96%	100%
1-5 Years of Experience	44%	82%	95%	100%	100%
5 More Years of Experience	100%	100%	100%	100%	100%

Figure 6.16 Answers to the question about user satisfaction for Case 4 by experience



	Yes	Not sure	No
School Experience	54%	31%	15%
1-5 Years of Experience	63%	25%	12%
5 More Years of Experience	100%	0	0

Figure 6.17 Answers to the question regarding controls over display for Case 4 by experience



	Yes	Not sure	No
School Experience	54%	85%	100%
1-5 Years of Experience	63%	88%	100%
5 More Years of Experience	100%	100%	100%

Figure 6.18 Accumulative percentage of user's desire for more controls over display for Case 4 by experience

Case 4

Similar approaches are used to analyze data for Case 4. Figure 6.15 and 6.16 indicate a similar result as that for Case 3, which is users with more work experienced indicated more satisfaction with the "malleable frame" system. Also experienced users seem to like the idea to have more controls over display (See Figure 6.17 and 6.18).

6.7 Hypothesis Test

The methodology for testing hypothesis follows a formal procedure of statistical analysis. The formal procedure for testing hypotheses about two population means normally has five steps (Minium, & Clarke, 1982, Triola, 1989). They are

1. Formulating the statistical hypothesis and selecting a level of significance.
2. Determining a desired sample size and selecting samples.
3. Calculating sample statistics.
4. Identifying the region of rejection.
5. Making statistical decisions and conclusions.

Following sections will discuss each of the five steps in order to draw a conclusion for this test.

6.7.1 Hypothesis

This research is interested in determining whether the "malleable frame" system is better than the standard system in terms of time. Thus the hypothesis is presented as following:

H_0: $\mu_m - \mu_s = 0$ (Null hypothesis)

H_a: $\mu_m - \mu_s < 0$ (Alternative hypothesis)

H_0 states "there is no difference between the 'malleable frame' system and the standard system in terms of time for making a decision." H_a states "the 'malleable frame' system is quicker than the standard system in terms of time for making a decision." μ_m and μ_s are population means of the "malleable frame" system and the standard system respectively.

A statistical decision will be made based on the following rule: (Byrkit, 1987, Mansfield, 1986)

"When the alternative hypothesis is $\mu_1 - \mu_2 \neq 0$, reject the null hypothesis if t exceeds $t_{\alpha/2}$ or less than - $t_{\alpha/2}$. When the alternative hypothesis is $\mu_1 - \mu_2 < 0$, reject the null hypothesis if $t < -t_\alpha$. When the alternative hypothesis is $\mu_1 - \mu_2 > 0$, reject the null hypothesis if $t > t_\alpha$ (Mansfield, 1986, p349)."

Where t_α can be obtained from Student's t distribution included in many statistics books; and t is obtained from calculations by the SPSS tool.

The level of significance, which specifies how rare a sample result must be in order to reject a hypothesis, is commonly set at either 0.01 or 0.05. Usually most research selects 0.05 (Minium, & Clarke, 1982, Byrkit, 1987, Triola, 1989). This research will accept 5% level of significance (or 95% confidence level).

6.7.2 Desired Sample Size and Selected Sample Size

As stated earlier, a desired sample size can be decided either by using the formula or using a size of 30 or more (Marks, 1997). This research uses a sample size of 46.

6.7.3 The Standard System vs the "Malleable Frame" System Statistical Analysis

Data are analyzed by SPSS with a level of significance of 5% (or 95% confidence level). Results are shown in Table 6.8 in which "SS" stands for "Standard System" and "MFS" stands for "Malleable Frame System. "

Table 6.8 The Result of Statistical Analysis

	Pair One		Pair Two		Pair Three	
	Case 1 (SS)	Case 3 (MFS)	Case 2 (SS)	Case 4 (MFS)	Average (SS)	Average (MFS)
Mean	58.54	36.59	42.52	37.96	51.11	37.15
Standard Deviation	33.06	14.25	22.23	19.99	21.87	14.08
Standard Error of Mean	4.88	2.10	3.28	2.95	3.22	2.08
Pearson's R	-0.046		0.15		0.24	
Degree of Freedom	45		45		45	
t Value	-4.07		-1.12		-4.11	

Pearson's R is a measure of linear association between two variables. The value of R ranges between -1 (a perfect negative relationship in which all points fall on a line with negative slope) and +1 (a perfect positive relationship in which all points fall on a line with positive slope). A value of 0 indicates no linear relationship.

6.7.4 Normalized Comparison Test

In order to reduce variance, a further normalized test was conducted by using pair 3 (average cases) and eliminating data sets that have large deviation. The criterion used for eliminating data is to reduce the data range by 20%. For example, the data range for the standard system is from 13 to 102 (see Table 6.4); while it is 17 to 84 (see Table 6.4) for the "malleable frame" system. Normalizing means that data falling in the range of 0%-10% and 90%-100% are removed. Consequently, the data range for the standard

system is reduced to 22 to 93 and the data range for the "malleable frame" system is reduced to 24 to 77. The normalized t-test will only use data within the new data ranges for each case. Table 6.9 shows the data sets conforming to the new data ranges.

Table 6.9 Normalized Data Sets for the Average Cases

Average SS	Average MFS
71	72
56	41
27	30
46	42
36	31
50	26
44	30
65	25
46	42
32	59
84	50
90	38
91	53
31	42
33	40
53	36
50	27
55	30
41	33
24	42
76	41
51	49
68	28
68	28
55	37
35	36
42	34
58	36
76	37
77	26
60	35
41	33
39	41

By using SPSS, following statistics are obtained (See Table 6.10).

Table 6.10 Statistics for the normalized test

	Sample Statistics	
	Malleable Frame System	**Standard System**
Mean	37.88	53.67
Standard Deviation	10.13	18.25
Standard Error of Mean	3.18	1.77
Degree of Freedom	32	32
Person's R	0.115	
t - Value	-4.57	

6.7.5 Sample Size Analysis

The population distribution is assumed to be normal and the following equation can be used to estimate a desired sample size.

$$n = (Z_{\alpha/2} * \sigma / E)^2$$

Where, α is the level of significance; σ is the standard deviation and E is called "maximum error".

Also it is assumed that the acceptable maximum error, E, may be 5 seconds, 8 seconds, and 10 seconds. The level of significance is 0.1 and 0.05.

Table 6.8 shows that 33.06 is the maximum standard deviation, which will be used to estimate sample size. Table 6.11 shows the results of calculation according to the equation shown above.

Table 6.11 Sample Size Analysis by Level of Significance and Maximum Error

	Maximum Error (E)		
Level of Significance	**5 (seconds)**	**8 (seconds)**	**10 (seconds)**
0.10	118	46	29
0.05	168	66	42

The results shown in Table 6.11 indicate that when using the 0.05 level of significance (or 95% confidence level), the desired sample size should be 168, 66, and 42 corresponding to 5 seconds, 8 seconds and 10 seconds of maximum error. The sample size of 46 used in this research can expect the maximum error of 10 seconds.

On the other hand, with the sample size of 46, it is 95% confident that the sample size is acceptable with a maximum error of 10 seconds; or it is 90% confident that the sample size is acceptable with maximum error of 8 seconds. The sample of the normalized test is acceptable with 90% confidence with a maximum error of 10 seconds.

6.7.6 The Region of Rejection

With $\alpha = 0.05$ (level of significance) and df = 45 (degree of freedom), t_α will be 1.679 according to Student's t distribution (Minium, & Clarke, 1982).

For the "normalized" test, with $\alpha = 0.10$ (level of significance) and df = 32 (degree of freedom), t_α will be 1.308 according to Student's t distribution.

6.7.7 Statistical Decisions

Based on above analysis, the following statistical observations can be made.

1. **Pair One: Case 1 and Case 3**

   Since $t = -4.07$ and $-t_\alpha = -1.679$, $t < -t_\alpha$ becomes with a level of significance of 0.05 (or 95% confidence level). Therefore, the null hypothesis is rejected, indicating that a significant difference exists between the standard system and the "malleable frame" system in terms of the time. In other words, according to these two cases, the time needed by persons using the "malleable frame" system is significantly less than the time needed by persons using the standard system.

2. **Pair Two: Case 2 and Case 4**

   Since $t = -1.12$ and $-t_\alpha = -1.679$, $t < -t_\alpha$ is not true at the significance level of 0.05 (or 95% confidence level). Therefore, the null hypothesis is accepted, which means that there is no significant difference in terms of time between using the standard system and by the "malleable frame" system. So in this case, using the "malleable frame" system is not faster than using the standard system to make a decision.

3. **Pair Three: Two average cases**

   Since $t = -4.11$ and $-t_\alpha = -1.679$, $t < -t_\alpha$ is true at the significance level of 0.05 (or 95% confidence level). Therefore the null hypothesis is rejected, indicating a significant difference exists between the standard system and the "malleable frame" system in terms of the time.

   For the "normalized" test, since $t = -4.57$ and $-t_\alpha = -1.308$, $t < -t_\alpha$ is true. Therefore, the null hypothesis is rejected, indicating a significant difference exists between the standard system and the "malleable frame" system as well.

6.8 Summary

This chapter focuses on the testing of hypothesis by setting up two types of test systems. One system simulates a system without malleability and the other simulates a system with malleability.

Sample data are collected from BCN graduate students and seniors most of whom have a good knowledge about change orders. Collected data are analyzed using standard statistical tools and the research hypothesis is tested.

Statistical analysis showed that in two of the three cases tested the "malleable frame" system was significantly faster in terms of the time it took the user to decide whether or not the change involved cost or not. However, in the case that document viewer's local information system does not have information about the item that the document has discussed, the results indicated that the "malleable frame" system will not always improve the efficiency of document processing. Overall, the results suggested that if the document processing requires local information and the information is available, using a "malleable frame" system is at least not slower that using a standard system.

As to user satisfaction, results indicated that most respondents were very satisfied with the "malleable frame" system and reported that the "malleable frame" system was helpful (96% in Case 3 and 94% in Case 4). However, many of them are not clear as to whether they need more control over the information display. Such results were observed in each of the knowledge groups, i.e. 5 or more years of experience, 1 to 5 years of experience and school experience. In addition, comparisons between different knowledge indicated that users with more work experience seemed to be more satisfied with the "malleable frame" system and more interested in having control over the information display.

CHAPTER 7
CONCLUSION

The objectives of this research have been stated as: (1) to test the feasibility of a "malleable frame" system based on currently available technology; (2) to test if a system with malleability is better in terms of time to complete document processing than a system without malleability. Thus conclusions will be drawn from the both.

7.1 Technical Feasibility

In order to evaluate the feasibility of implementing such a system, this research investigated related design methodologies, implementation tools, and results of the implementation.

7.1.1 Design Methodologies

There are two types of design methodologies involved in this research, one for the design of a "malleable frame" and the other for a "malleable frame" system.

Methodology for the Design of A "Malleable Frame"

A "malleable frame" is a neutral document format. In the Web computing environment, a meta-language, called eXtended Markup Language (XML), is being developed by the World Wide Web Consortium (W3C). XML, a sub-set of SGML (Standard Generalized Markup Language), can be used for develop system independent neutral data format. Methodologies for developing SGML applications are well

documented (Van Herwijnen, 1994, Travis, & Waldt, 1995, Maler, & Andaloussi, 1996, Donovan, 1997).

In this research a top down approach is used to develop a sample request for change order proposal DTD. Such an approach is very straightforward and the results are good enough to serve as a neutral data format. However, one of the possible limitations is that information included in the DTD is limited to what appears on the document themselves. Thus if a set of documents that is used for document analysis is not complete enough, the derived DTD will most likely contain flaws.

There are other approaches that can be used such as a bottom up approach and a combined approach. A bottom up approach looks at the entire business process that a certain type of document is involved in rather than only a particular set of documents. Object oriented analysis will be applied to find out all of the objects that are involved in the entire process. In this way, the bottom up approach provides a more comprehensive scope from which a particular type document DTD can be derived.

A combined approach lies some where between the top down approach and the bottom up approach. As of this writing, the author of this dissertation is using this approach in developing construction document schemas (Similar to DTD) for a construction software company.

Methodology for the Design of A "Malleable Frame" System

The "malleable frame" system is a dynamic hypermedia system (Zhu, 1999). This area has been well studied and documented. Besides some previous methodologies such as the g-IBIS (Conklin, & Begeman, 1988) and the Dexter Hypertext Reference Model (Halasz, & Schwartz, 1990, Halasz, & Schwartz, 1994), three most influential design

methodologies are used today (Garzotto, Paolini, & Schwabe, 1995, Schwabe, Rossi, & Barbosa, 1996, Isakowitz, Stohr, & Balasubramanian, 1995). They are Hypermedia Development Method (HDM), Object Oriented Hypertext Development Methodology), and RMM (Relationship Management Methodology). Although they are different in details, the three methodologies bear very strong similarities, which can be summarized as:

- Separate hypermedia design and implementation
- Modularized hypermedia applications with conceptual schema, navigational schema and presentation schema

Following the three-schema approach, the Kaleidoscope software was previously developed (Zhu, 1999).

7.1.2 Implementation Tools

Contemporary computer technology has provided a rich set of implementation tools for solving our problems. As far as this research is concerned, three types of tools are critical i.e. an XML parser, XML and database integration tools and Web oriented programming language.

XML Parsers

There are many XML parsers available for free. Many of them only do document validations. However, there are two XML parsers that are capable of both validating a XML document and generating a parse tree of the XML document. These two parsers have developed by Microsoft (Paoli, Schach, Lovett, Layman, & Cseri, 1997) and IBM (http://www.IBM.com) respectively.

This research applies the IBM parser because it strictly complies with the W3C Document Object Model (DOM).

Microsoft IE4 uses a different Document Object Model than that of the W3C's. However, IE5 has started to support the W3C's DOM with some extensions.

XML and Database Integration Tools

Many database vendors have moved quickly to incorporate XML technology into their database technology. ColdFusion is the first to propose the integration of XML and database technology by using WDDX (Web Distributed Data eXchange). Oracle, Informix, Object Design and POET are also moving to that direction. Although it takes a while for the computer industry to complete absorb XML technology and provide full-brown applications for end users, such integration is the trend and will prevail soon (Mendel, 1999).

Programming Tools

Besides tools discussed above, the implementation of Kaleidoscope is completed by using Java programming. Java programming language is designed for Internet/Web applications. It provides a rich set of classes dealing with the intenet/Web programming, user interface programming, concurrent programming and many other applications. These features make Java programming language an ideal tool for the implementation of Kaleidoscope.

That this research uses Java for implementation does not mean other technologies are not available or not appropriate. On the contrary, other Web tools such DHTML and ASP can be used perfectly to implement such a system.

Results of the Implementation

The system, Kaleidoscope, reveals that:

- Document Interpretation. A construction document prepared in a neutral format, an XML format, can be precisely interpreted by Kaleidoscope. The design of document structure will eventually affect the malleability of a document. For example, if a "sender" and his "address" are combined as one element, the Kaleidoscope will have no way to retrieve other information, for example a Web page, of the sender. This indicates that the DTD that decides the structure of a construction document is crucial for the degree of malleability of a document.
- Information Integration. The integration of document information and local information is achieved by sharing a common information index system, such as the CSI Masterformat. Although this research does not actually retrieve information from a database, based on the CSI five-digit system the Kaleidoscope can efficiently and effectively integrate related information from a document and a local source. Therefore it can be concluded that current construction information classification systems such as the CSI Masterformat can be used as a neural information index system.
- User Interaction. User interactions are an important part of malleability. One of the major things to show malleability is that a user can manipulate document information and related local information according his/her needs. This is achieved by providing users with a mixed index that can access to all related local information. Besides the mixed index, Kaleidoscope also

provides a single index that allows users to access to one type of information a time and a document index that allows users to tailor the presentation of a particular type of document. Technically, these indexes are enough for uses to manipulate information.

7.2 Hypothesis Testing

The purpose of the hypothesis testing is to investigate the superiority of a "malleable frame" system to a standard system. This objective is achieved by comparing two systems, one with malleability and the other without. Participants in the tests were also asked to answer questions about their level of satisfaction with the two systems as well.

At a level of significance of 0.05 (or 95% confidence level), the original hypothesis was rejected by two test cases (Pair One and Pair Three) and was accepted by one case (Pair Two). In addition, the hypothesis was also rejected by the normalized data at a level of significance of 0.1 (or 90% confidence level). Further analysis indicated that in some situations when the user's local systems did not have the information required for processing a document, or that the document processing did not require any local information, there was no significant difference between the two systems. This means that in those situations, the system with malleability is not actually very helpful in terms of time. However, statistical analysis in the previous chapter also indicated that people using a system with malleability would be significantly faster than those using a system without malleability when processing construction documents if the required local information is available. Overall, it is still inconclusive as to whether the "malleable

frame" system is better than the standard system. Further data are required to make conclusive decisions.

The sample size used in this research is acceptable at a level of significance of 0.05 with a maximum error of 10 seconds.

7.3 User Satisfaction

With respect to user satisfaction, most people (96% in Case 3 and 94% in Case 4, see Figure 6.5) reported that the "malleable frame" system was helpful by putting a Request for Change Order Proposal together with related local information in the same screen. In contrast, only 61% of the participants (See Figure 6.6) reported that they needed more control over the display of the information. This type of pattern was also observed in each group with different levels of knowledge, i.e. school experience, 1 to 5 years of experience and 5 or more years of experience (See section 6.6.4).

In addition, results showed that persons with more work experience found the "malleable frame" system to be more helpful and they also desired more controls over the "malleable frame" system and the information it presented (See section 6.6.5).

CHAPTER 8
RECOMMENDATIONS FOR FURTHER STUDIES

Integration of different data sets by using a neutral document format and a standard construction information index system is the goal of this research. Due to the large scope of such a goal, this particular research focused on part of this large picture by investigating the technical feasibility of implementation and the advantages of a system with malleability. Consequently, there are certain limitations to this research. During the development of this research some new ideas were generated and needed to be investigated. All these will be discussed below. The discussion will be grouped into three categories, topics on the neutral document format, topics on system design and topics on system testing.

8.1 Topics on the Neural Document Format

8.1.1 Document Analysis

One of the most important steps in developing a neutral document format is to identify elements that need to be included and tagged. This step also affects the final data granularity of a document and thus the access level. Consequently, the data granularity and the access level will affect the degree of malleability.

For this research, document elements are generalized from a set of documents of the same type, namely a CSI document and a customized document, a Request for Change Order Proposal. This approach might not be enough, because those document

formats are designed for human use not for a machine to present its malleability. This raises the question about how such a method eventually will limit a system's malleability.

Thus it is suggested here that it may be better for further studies to take a bottom up approach developing a comprehensive document object model based on available models such as the IFC (Industrial Foundation Classes) data model or by using case scenarios. Consequently, objects in a document will be more semantically rich.

8.1.2 Construction Markup Language

DTDs or XML schemas define the vocabulary set (tags) and document structures for a particular application domain. Although this research only presents a method to develop a DTD for a Request for Change Order Proposal, which can be regarded as a subset of a construction markup language, the significance of having such a construction markup language becomes very obvious. A construction markup language defines the entire document set in terms of the document structure and the vocabulary set for the construction industry. With such a standardized language, construction information systems can achieve data interoperability through a Web based "front-end" integration strategy, which is more flexible.

As of this writing, a few companies such as the Bentley System and Timberline Software are starting such efforts under the umbrella of Microsoft's BizTalk framework. The author of this dissertation is currently working for the Timberline Software Corporation developing a large subset of the construction markup language that is related to Timberline software applications.

8.2 Topics on System Design

8.2.1 Interface

The user interface was not a main focus of this study. One of the problems with developing any other "malleable frame" systems is the arrangement of the indexes. It might be better if we combine all three indexes, the document index, the single index and the mixed index into one or some other form that the user may like.

Focusing only on the mechanisms of a "malleable frame" system, this research does not investigate what kinds of user interface features should be built into the system. Further studies may need to work on this area too because this research has proved that technically a "malleable frame" system is feasible and more efficient in some cases.

8.2.2 User Needs

User's information needs are very complicated. Different users may need different local information even for processing the same construction document. This research did not differentiate between user's specific information needs and simply assumed that schedule information is all that is needed. It would be helpful if the system can keep track of each user's experience in dealing with a particular type of document to identify user's specific information needs.

8.2.3 Database

Kaleidoscope is not built upon any database systems. It is assumed in this research that local information that in most cases is stored in a relational database can be exported from the database and converted into XML format. Theoretically it is feasible. However, technically this relies on database vendors' efforts to incorporate XML technology into their database systems.

Essentially, a "malleable frame" system needs to be built around some type of database system. Therefore, it would be a great step forward if further studies can investigate whether a neutral (shared) information index system based on CSI (Construction Specification Institute) Masterformat is technically feasible for the purpose of integrating local information.

8.3 Topics on System Testing

8.3.1 Testing

In order to obtain a pair-wise comparison, this research uses pairs with two cases. No matter how similar one prepares the two cases, some difference will exist. It is hard to predict and evaluate how the differences between the two cases will affect the test variable. So it would be interesting to take another approach. The new approach will use the same case for the two test systems. The test process will be first let users do tests on either the standard system or the "malleable frame" system. After a certain period of time such as several months, let the users do the same case but on the other system. The assumption of this approach is that after a certain period of time the users will not remember the details of the tests they completed earlier so that the second test will not be biased. Of course, the difficulties lie in using the same sample in the second test and determining the time period to make the assumption reasonable.

8.3.2 Testing More Features Quantitatively

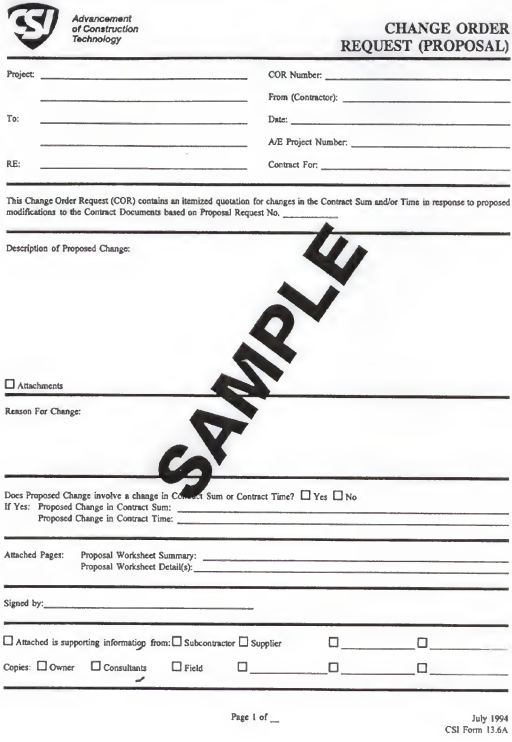
This research only collects data for time and user satisfaction. It would be very interesting if data on users' behavior can be collected. Examples include what information is selected as a default view for different users to deal with a same type of documents, how many times a user needs to change a default view to find a answer, and

what kind of indexes is the most used, etc. This will be helpful in understanding the user's specific information needs.

8.3.3 Testing the Whole Process of Document Processing

As mentioned earlier, the whole process of construction document processing is composed of many steps of decision-making. It would be interesting if a study could be conducted to test the whole process of document processing. Such a test requires a more sophisticated test system, and well-designed and carefully selected test cases.

APPENDIX A
SAMPLE CONSTRUCTION DOCUMENTS AND CSI MASTERFORMAT



Advancement of Construction Technology

CHANGE ORDER REQUEST (PROPOSAL)

Project: _____ COR Number: _____

_____ From (Contractor): _____

To: _____ Date: _____

_____ A/E Project Number: _____

RE: _____ Contract For: _____

This Change Order Request (COR) contains an itemized quotation for changes in the Contract Sum and/or Time in response to proposed modifications to the Contract Documents based on Proposal Request No. _____

Description of Proposed Change:

SAMPLE

☐ Attachments

Reason For Change:

Does Proposed Change involve a change in Contract Sum or Contract Time? ☐ Yes ☐ No

If Yes: Proposed Change in Contract Sum: _____

Proposed Change in Contract Time: _____

Attached Pages: Proposal Worksheet Summary: _____

Proposal Worksheet Detail(s): _____

Signed by: _____

☐ Attached is supporting information from: ☐ Subcontractor ☐ Supplier ☐ _____ ☐ _____

Copies: ☐ Owner ☐ Consultants ☐ Field ☐ _____ ☐ _____ ☐ _____

Page 1 of __

July 1994
CSI Form 13.6A

Figure A.1 A CSI sample of change order request (proposal)

Proposal Request

Flagler Hospital – phase 1

OWNER	❑
ARCHITECT	❑
CONTRACTOR	■
FIELD	❑
OTHER	❑

PROJECT:	Flagler Hospital 1234 NW 123 St. Gainesville, FL 32456
OWNER:	University of Florida Gainesville, FL 32603 Tel: (352)232 6785 Fax: (352)232 7584
ARCHITECT:	Albert Design 2345 NW 345Rd. Gainesville, FL 32456 Tel: (352)456 7891 Fax:(352)456 5647
CONTRACTOR:	Gator Construction 3456 SE 23St. Gainesville, FL 32465 Tel: (352)345 6789 Fax:(352)345 9876

PROPOSAL REQUEST NO: 23

PROJECT NUMBER: 94345

DATE: 1/12/98

CONTRACT DATE: 1/10/98

Please submit an itemized quotation for changes in the Contract Sum and/or Time incidental to proposed modifications to the Contract Documents described herein. All items listed below may be clarifications only without affecting cost or schedule.

THIS IS NOT A CHANGE ORDER NOR A DIRECTION TO PROCEED WITH THE WORK DESCRIBED HEREIN.

DESCRIPTION:

CHILLED WATER FOR PHASE II

Provide chilled water capped in the ceiling on the third floor of the new patient tower connector as request by the GRGV's PR#M09.

Signature:

Issued by __xxx_____ Date : __4/12/98_____

Figure A.2 A customized sample of request for change order proposal

CHANGE ORDER

AIA DOCUMENT G701

OWNER ☐
ARCHITECT ☐
CONTRACTOR ■
FIELD ☐
OTHER ☐

PROJECT: **Palmetto Shopping Center**
(name, address) **4400 W. Absent Ave.**
Gainesville, FL 32601

CHANGE ORDER NUMBER: **#1**

DATE: **Oct 5, 1999**

TO CONTRACTOR: **LL Construction Company**
(name, address) **123 University Ave.**
Gainesville, FL 32601

ARCHITECT'S PROJECT NO: **1234**

CONTRACT DATE: **September 1, 1999**

CONTRACT FOR

The Contract is changed as follows:

1. To add 5 concrete equipment pads for A/C units

PLEASE SEE ATTACHED DOCUMENTATION

Not valid until signed by the Owner, Architect and Contractor.

The original **(Contract Sum)** was	**$ 200,209**
Net change by previously authorized Change Orders	**$ 0.00**
The **(Contract Sum)** prior to this Change Order was	**$ 200,209**
The **(Contract Sum)** will be **(increased)** by this Change Order in the amount of	$ 1,782
The new **(Contract Sum)** including this Change Order will be	**$ 201,991**
The Contract Time will be **(increased)** by five (7) days.	
The date of Substantial Completion as of the date of this Change Order therefore is	**(7) days beyond the original date of substantial completion.**

NOTE: This summary does not reflect changes in the Contract Sum, Contract Time or Guaranteed Maximum Price which have been authorized by Construction Change Directive.

CREATIVE DESIGN, INC ARCHITECT	LL CONSTRUCTION COMPANY CONTRACTOR	BROWN GROUP OWNER
2805 9TH STREET NORTH S. ADDRESS	123 UNIVERSITY AVE. ADDRESS	3201 SW 35TH PLACE ADDRESS
PETERSBURG, FL 33704	GAINESVILLE, FL 32601	GAINESVILLE, FL 32667
By	By	By
Date: OCTOBER 5, 1999	Date: OCTOBER 5, 1999	Date: OCTOBER 5, 1999

AIA CAUTION: You should sign an original AIA document which has this caution printed in black. An original assures that changes will not be obscured as may occur when documents are reproduced.

AIA DOCUMENT G701 • CHANGE ORDER • 1987 EDITION • AIA • 1987 • THE AMERICAN INSTITUTE OF ARCHITECTS
1735 NEW YORK AVE., NW., WASHINGTON, DC 20006 G701-1987

G701-1987

WARNING: Unlicensed photocopying violates U.S. copyright laws and is subject to legal prosecution.

Figure A.3 A AIA sample of change order

APPENDIX B
SCREEN SHOTS OF KALEIDOSCOPE

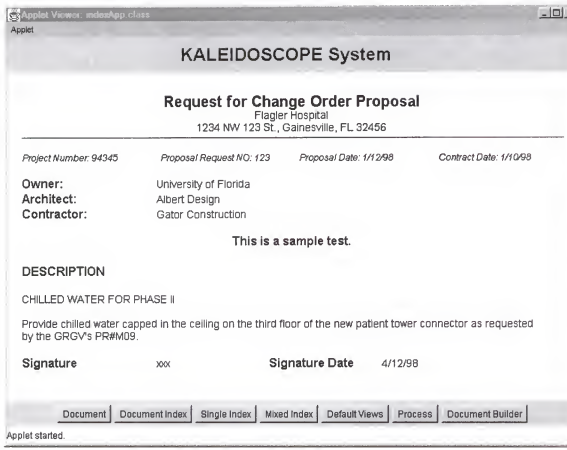


Figure B.1 An original document mode

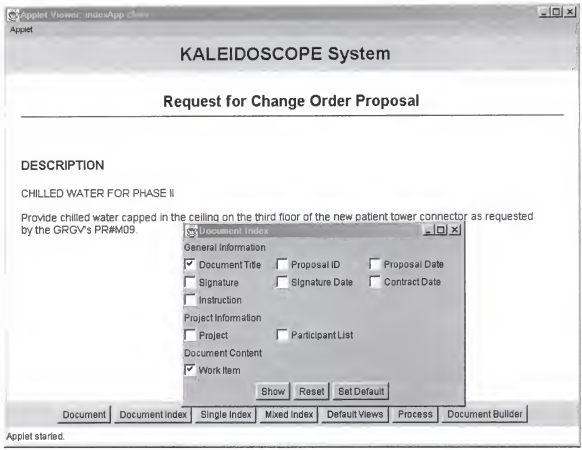


Figure B.2 A document index mode

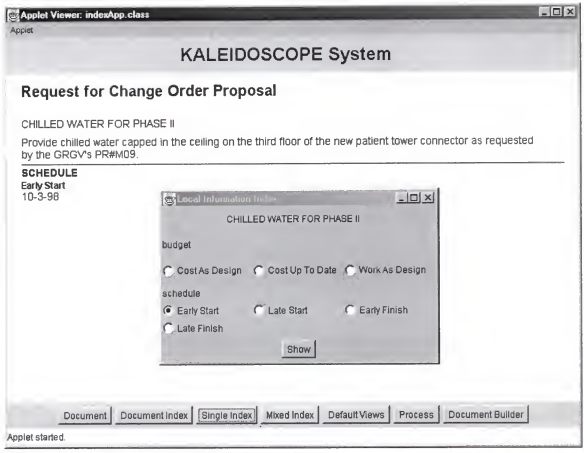


Figure B.3 A local information index mode

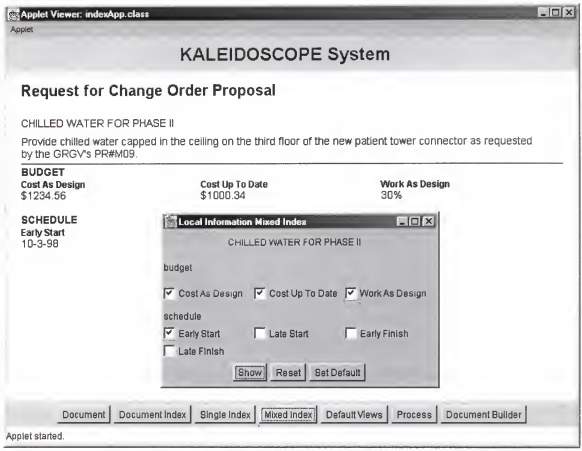


Figure B.4 A local information mixed index mode

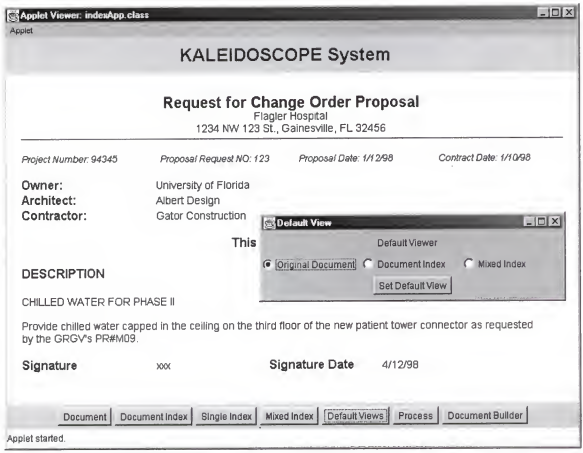


Figure B.5 A default view setting mode

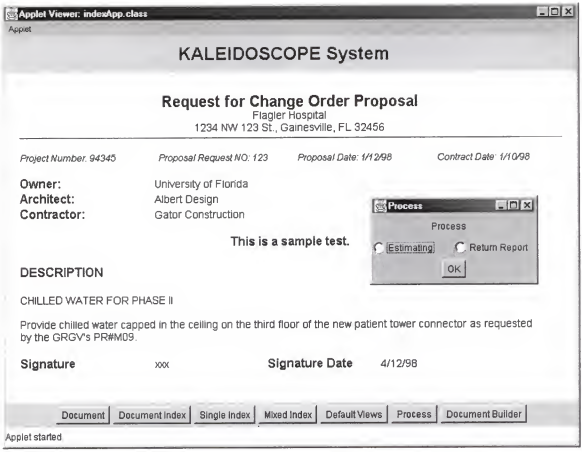


Figure B.6 A process mode

APPENDIX C
THE TEST SYSTEM

Major Screen Shots

Following are a series of screen shots of the test system.

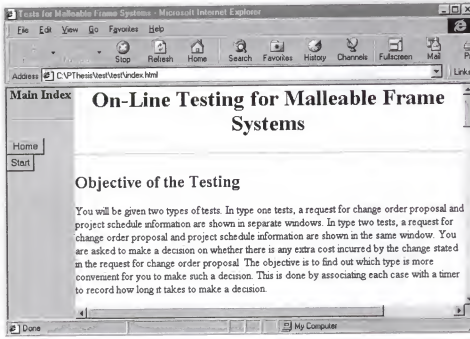


Figure C.1 General introduction screen

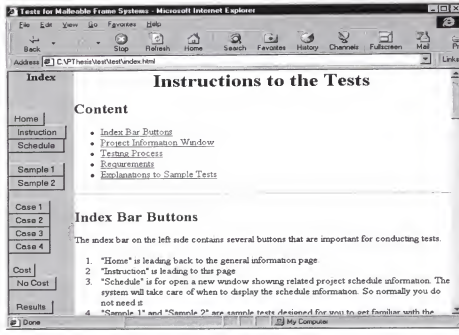


Figure C.2 Instructions to the tests

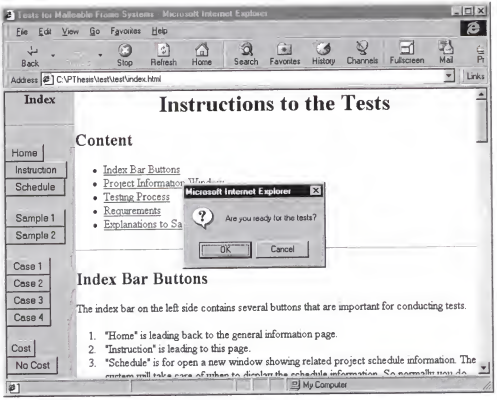
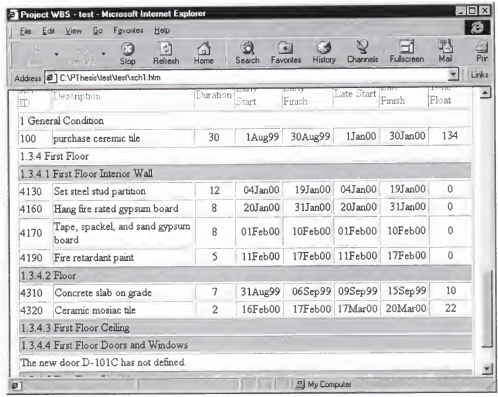


Figure C.3 A dialogue box controlling the start of tests



ID	Description	Duration	Early Start	Early Finish	Late Start	Late Finish	Float
1 General Condition							
100	purchase ceremic tile	30	1Aug99	30Aug99	1Jan00	30Jan00	134
1.3.4 First Floor							
1.3.4.1 First Floor Interior Wall							
4130	Set steel stud partition	12	04Jan00	19Jan00	04Jan00	19Jan00	0
4160	Hang fire rated gypsum board	8	20Jan00	31Jan00	20Jan00	31Jan00	0
4170	Tape, spackel, and sand gypsum board	8	01Feb00	10Feb00	01Feb00	10Feb00	0
4190	Fire retardant paint	5	11Feb00	17Feb00	11Feb00	17Feb00	0
1.3.4.2 Floor							
4310	Concrete slab on grade	7	31Aug99	06Sep99	09Sep99	15Sep99	10
4320	Ceramic mosiac tile	2	16Feb00	17Feb00	17Mar00	20Mar00	22
1.3.4.3 First Floor Ceiling							
1.3.4.4 First Floor Doors and Windows							
The new door D-101C has not defined							

Figure C.4 Related schedule information

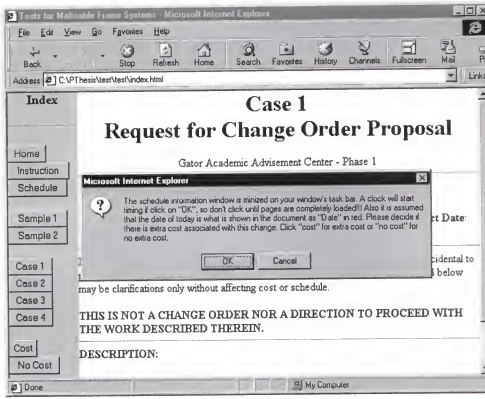


Figure C.5 A dialogue box controlling the start of timing

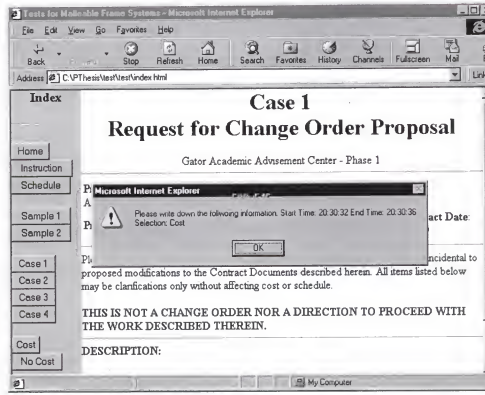


Figure C.6 A dialogue box showing a test result

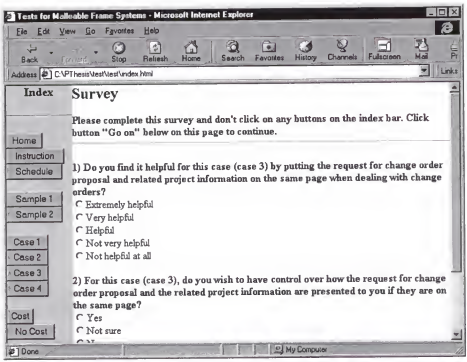


Figure C.7 Survey to assess user satisfaction with the "malleable frame" system

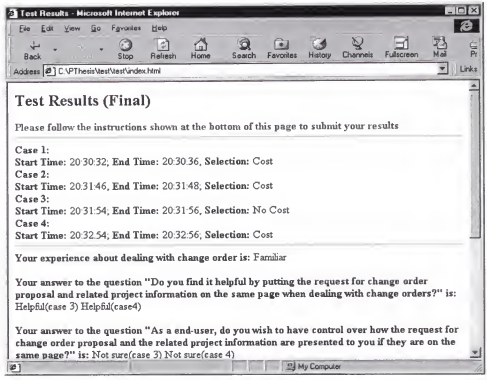


Figure C.8 Sample screen of final results

Scenario

The construction project for the tests is a three-story building called Gator Academic Advisement Center. The floor plan of the first floor is shown below. There are two types of tests that will focus on changes affecting one room, Room 101. The drawing, Figure C.9, shows the floor plan and where Room 101 is located.

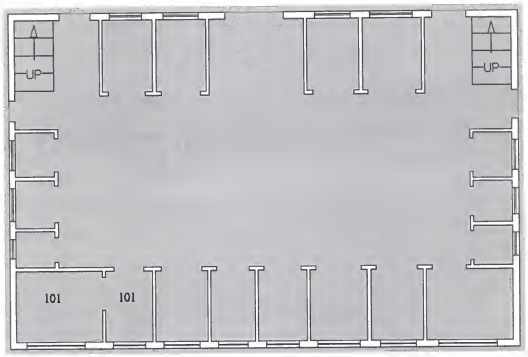


Figure C.9 The floor plan

Figure C.10 shows some detailed information about Room 101.

Request for Change Order Proposals will be given regarding changes to Room 101. What testers need to do, is to decide whether there is any extra cost incurred due to the proposed changes.

Certain assumptions are made in order to complete the tests. These assumptions are as follows:

1. Only schedule information affects cost changes.

2. The date on the Request for Change Order Proposal is the date of today.
3. All partition walls related to this room are referred to as "First Floor Interior Wall" in the project schedule (Figure C.10).
4. All exterior walls related to this room are referred to as "First Floor Exterior Wall" in the project schedule (Figure C.10).
5. For the test purpose, project schedule only includes activities that are related to changes.
6. Room 101 is on the first floor.

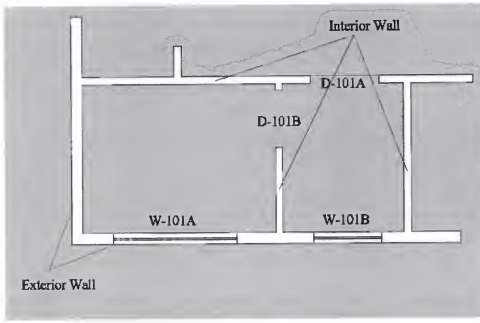


Figure C.10 Room 101

Flow Control

It is important that each user follows the same flow of steps during testing. To achieve this objective a handful of user interface features such dialogue boxes and prompts are used. Figure C.11 shows the designed flow of test steps.

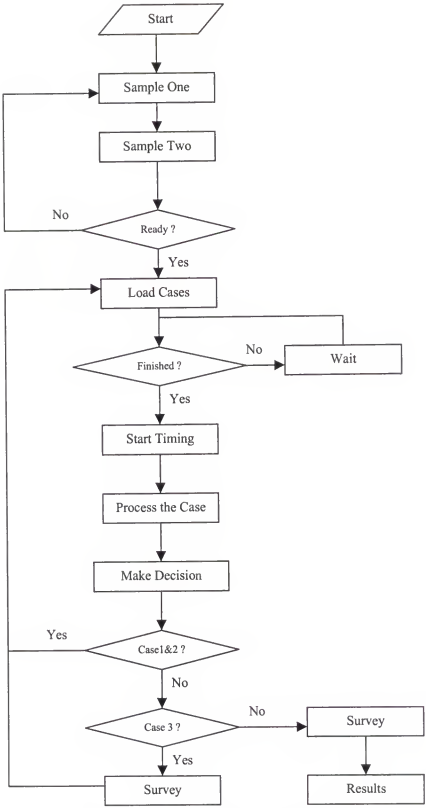


Figure C.11 Flowchart of test steps

Schedule

The scheduling of related activities for Case One and Case Two is in Table C.1.

Table C.1 Schedule of related activities for Case One and Case Two

Act. ID	Description	Duration	Early Start	Early Finish	Late Start	Late Finish	Total Float
1 General Condition							
100	purchase ceramic tile	30	1Aug99	30Aug99	1Jan00	30Jan00	134
1.3.4 First Floor							
1.3.4.1 First Floor Interior Wall							
4130	Set steel stud partition	12	04Jan00	19Jan00	04Jan00	19Jan00	0
4160	Hang fire rated gypsum board	8	20Jan00	31Jan00	20Jan00	31Jan00	0
4170	Tape, spackle, and sand gypsum board	8	01Feb00	10Feb00	01Feb00	10Feb00	0
4190	Fire retardant paint	5	11Feb00	17Feb00	11Feb00	17Feb00	0
1.3.4.2 Floor							
4310	Concrete slab on grade	7	31Aug99	06Sep99	09Sep99	15Sep99	10
4320	Ceramic mosaic tile	2	16Feb00	17Feb00	17Mar00	20Mar00	22
1.3.4.3 First Floor Ceiling							
1.3.4.4 First Floor Doors and Windows							
The new door D-101C has not defined.							
1.3.4.5 First Floor Plumbing							
1.3.4.6 First Floor HVAC							
4800	Rough in HVAC	2	20Jan00	21Jan00	03Feb00	04Feb00	10
4810	Inspect rough in HVAC	1	24Jan00	24Jan00	07Feb00	07Feb00	10
4820	Install thermostat	2	25Jan00	26Jan00	17Mar00	18Mar00	38
4830	Install grilles	1	26Jan00	26Jan00	08Feb00	10Feb00	10
4840	Install HVAC unit including A/C units	3	25Jan00	27Jan00	17Mar00	19Mar00	39
4850	Connect HVAC units including A/C units	1	28Jan00	28Jan00	20Mar00	20Mar00	38
4860	Test HVAC unit	1	29Jan00	29Jan00	21Mar00	21Mar00	39
1.3.4.7 First Floor Electrical							
1.3.10 Exterior Wall							
7800	Erect concrete unit masonry	25	27Oct99	30Nov99	27Oct99	30Nov99	0
7810	Bituminous damp-proofing	8	15Dec99	24Dec99	20Dec99	29Dec99	3
7820	Hang rigid insulation	8	27Dec99	05Jan00	30Dec99	10Jan00	3
7830	Place brick unit face masonry	20	06Jan00	02Feb00	11Jan00	07Feb00	3
7840	Set precast concrete panel	8	03Feb00	14Feb00	08Feb00	17Feb00	3
7850	Clean	7	15Feb00	23Feb00	18Feb00	28Feb00	3
7860	Set metal furring channel	10	01Dec99	14Dec99	06Dec99	17Dec99	3
7870	Set precast sill	8	03Feb00	14Feb00	08Feb00	17Feb00	3

Test Cases

Four different cases are used in the tests, two for the standard system and two for the "malleable frame" system.

Test Case One

Test Case One involves changing the position of the A/C unit in Room 101 (refer to Figure C.12). The height of the position and other conditions remain the same. In order to use the included project schedule (Table C.1), the issue date of the Request for Change Order Proposal is assumed to be March 1, 2000.

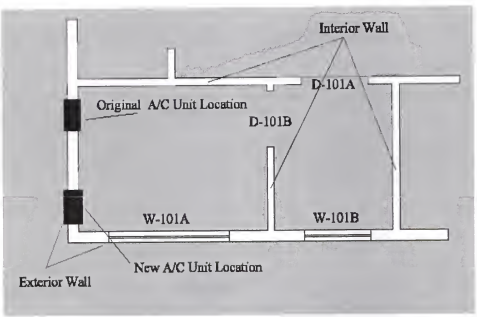


Figure C.12 Revision to the A/C unit in Room 101

Test Case Two

Test Case Two involves adding a new door to Room 101 (refer to Figure C.13 and Figure C.14).

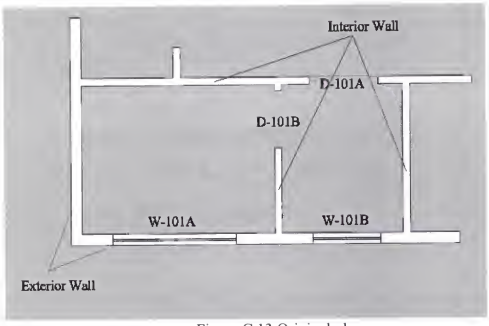


Figure C.13 Original plan

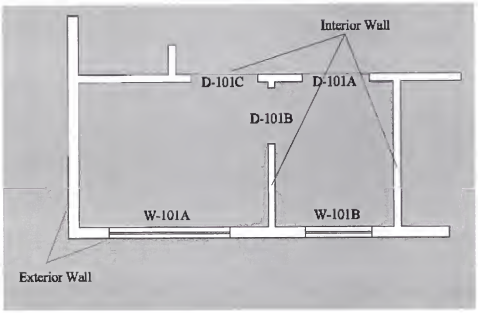


Figure C.14 Revised Plan

Test Case Three

Test Case Three involves changing the light switch location in Room 101 (refer to Figure C.15).

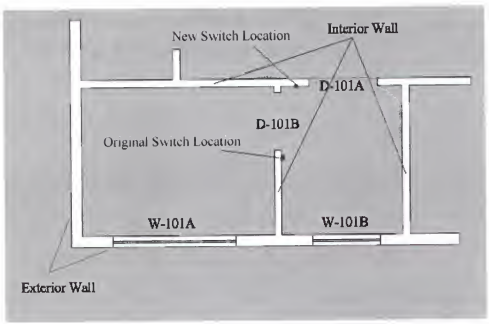


Figure C.15 Light switch location change

Since test case three is for the "malleable frame" system, the schedule information shown in Table C.1 is placed in the same with the document itself.

Test Case Four

Test case four is for adding a new window to room 101. Figure C.16 shows the location of the new window, W-101C.

Similarly, since test case four is for the "malleable frame" system as well the schedule information (Table C.2) is shown in the same window with the document.

Table C.1 Schedule information regarding light switch in Case Three

Act. ID	Description	Duration	Early Start	Early Finish	Late Start	Late Finish	Total Float
1.3.4.7 First Floor Electric							
4900	Rough in electrical	3	20Jan00	24Jan00	28Feb00	01Mar00	27
4910	Inspect rough in electrical	1	25Jan00	25Jan00	10Mar00	10Mar00	33
4920	Pull wire	3	26Jan00	28Jan00	13Mar00	15Mar00	33
4930	Install connect panel	2	31Jan00	01Feb00	17Mar00	20Mar00	34
4940	Install light fixtures	3	31Jan00	02Feb00	16Mar00	20Mar00	33
4950	Install electrical appliances	1	31Jan00	31Jan00	20Mar00	20Mar00	35
1.3.4.1 First Floor Interior Wall							
4130	Set steel stud partition	12	04Jan00	19Jan00	04Jan00	19Jan00	0
4160	Hang fire rated gypsum board	8	20Jan00	31Jan00	20Jan00	31Jan00	0
4170	Tape, spackle, and sand gypsum board	8	01Feb00	10Feb00	01Feb00	10Feb00	0
4190	Fire retardant paint	5	11Feb00	17Feb00	11Feb00	17Feb00	0

Table C.2 Schedule information regarding the exterior wall in Case Four

Act. ID	Description	Duration	Early Start	Early Finish	Late Start	Late Finish	Total Float
1.3.10 Exterior Wall							
7800	Erect concrete unit masonry	25	27Oct99	30Nov99	27Oct99	30Nov99	0
7810	Bituminous damp-proofing	8	15Dec99	24Dec99	20Dec99	29Dec99	3
7820	Hang rigid insulation	8	27Dec99	05Jan00	30Dec99	10Jan00	3
7830	Place brick unit face masonry	20	06Jan00	02Feb00	11Jan00	07Feb00	3
7840	Set precast concrete panel	8	03Feb00	14Feb00	08Feb00	17Feb00	3
7850	Clean	7	15Feb00	23Feb00	18Feb00	28Feb00	3
7860	Set metal furring channel	10	01Dec99	14Dec99	06Dec99	17Dec99	3
7870	Set precast sill	8	03Feb00	14Feb00	08Feb00	17Feb00	3
The new window is not defined in the original schedule							

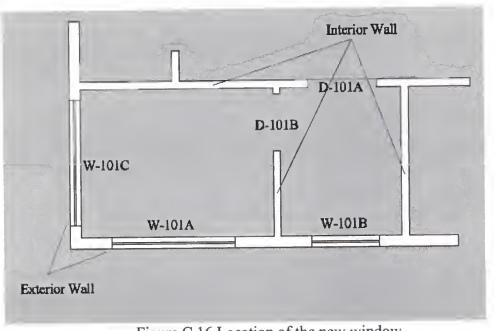


Figure C.16 Location of the new window

Survey Form

The following is the survey form used for collecting test data:

Survey Answer Sheet

Top of Form 1

Test time and selections:

	Case 1	Case 2	Case 3	Case 4
Start Time:				
End Time :				
Selection :				

1. Do you find it helpful when the request for change order proposal and related project information are on the same computer screen when dealing with change orders?

Case 3

- ○ Extremely helpful
- ○ Very helpful
- ○ Helpful
- ○ Not very helpful
- ○ Not helpful at all

Case 4

- ○ Extremely helpful
- ○ Very helpful
- ○ Helpful
- ○ Not very helpful
- ○ Not helpful at all

2. As an end-user, do you wish to have control over how the request for change order proposal and the related project information are presented to you, even when they are on the same computer screen?

Case 3

- ○ Yes
- ○ Not sure
- ○ No

Case 4

- ○ Yes
- ○ Not sure
- ○ No

3. Your knowledge about dealing with change orders is:

- ○ Excellent (more than 10 years of working knowledge of change orders)
- ○ Very familiar (5 - 10 years of working knowledge of change orders)
- ○ Familiar (1 - 5 years of working knowledge of change orders)
- ○ Not familiar (school experience)
- ○ Don't know at all

APPENDIX D
GLOSSARY

Acronym	Standard Name
ACTS	Advanced Construction Technology System
ADS	AutoCAD Development System
AEC	Architecture Engineering Construction
AGC	Associated General Contractors of America
AIA	American Institute of Architect
AIT	AutoCAD IGES Translator
ANSI	American National Standards Institute
API	Application Programming Interface
ASPE	American Society of Professional Estimators
ATLAS	Architectures Methodologies and Tools for Computer Integration Large Scale Engineering
BSCW	Basic Supported Collaborative Work
CAD	Computer Aided Design
CBS	Cost Breakdown Structure
CDATA	Character DATA
CESMM	Civil Engineering Standard Method of Measurement
CIC	Computer Integrated Construction
CICS	Construction Information Classification System
COKE	COnstruction Knowledge Expert
COM	Component Object Model
COMMIT	COMputer Models for the Building Industry in Europe
COP	Change Order Proposal
CPM	Critical Path Method
CSC	Construction Specification Canada
CSCW	Computer Supported Collaborative Work
DBMS	Database Management System
DHTML	Dynamic Hypertext Markup Language
DOM	Document Object Model
DTD	Document Type Definition
EBNF	Extended Backus-Naur Form
EJCDC	Engineers Joint Contract Document Committee
GSA	General Service Administration
HDM	Hypertext Design Model
HTML	HyperText Markup Language
IAI	Industry Alliance for Interoperability
ICON	Integration of Construction Information
IFC	Industry Foundation Class
IGES	Initial Graphics Exchanges Specification
IKIS-Safety	Integrated Knowledge Intensive System for Construction Safety and Health Performance Control
ISO	International Organization for Standardization
IT	Information Technology
KBDBI	Knowledge-Based Database Interface
KBSI	Knowledge-Based System Interface

MFS	Malleable Frame System
NDAM	Network Data Access Manager
OOHDM	Object-Oriented Hypertext Development Methodology
OPSI	Object-model based Project Information System
OSHA	Occupational Safety and Health Administration
PMICS	Project Management Information Control System
RCOP	Request for Change Order Proposal
RDF	Resource Description Framework
RFI	Request For Information
RRM	Relationship Management Methodology
SGML	Standard Generalized Markup Language
SS	Standard System
STEP	Standard for the Exchange of Product Model Data
XML	eXtended Markup Language
XSL	eXtended Style Language
UCI	Uniform Construction Index
URT	Uncertainty Reduction Theory
UUCI	United Classification for the Construction Industry
W3C	World Wide Web Consortium
WBS	Work Breakdown Structure
WDDX	Web Distributed Data Exchange
WWW	World Wide Web

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